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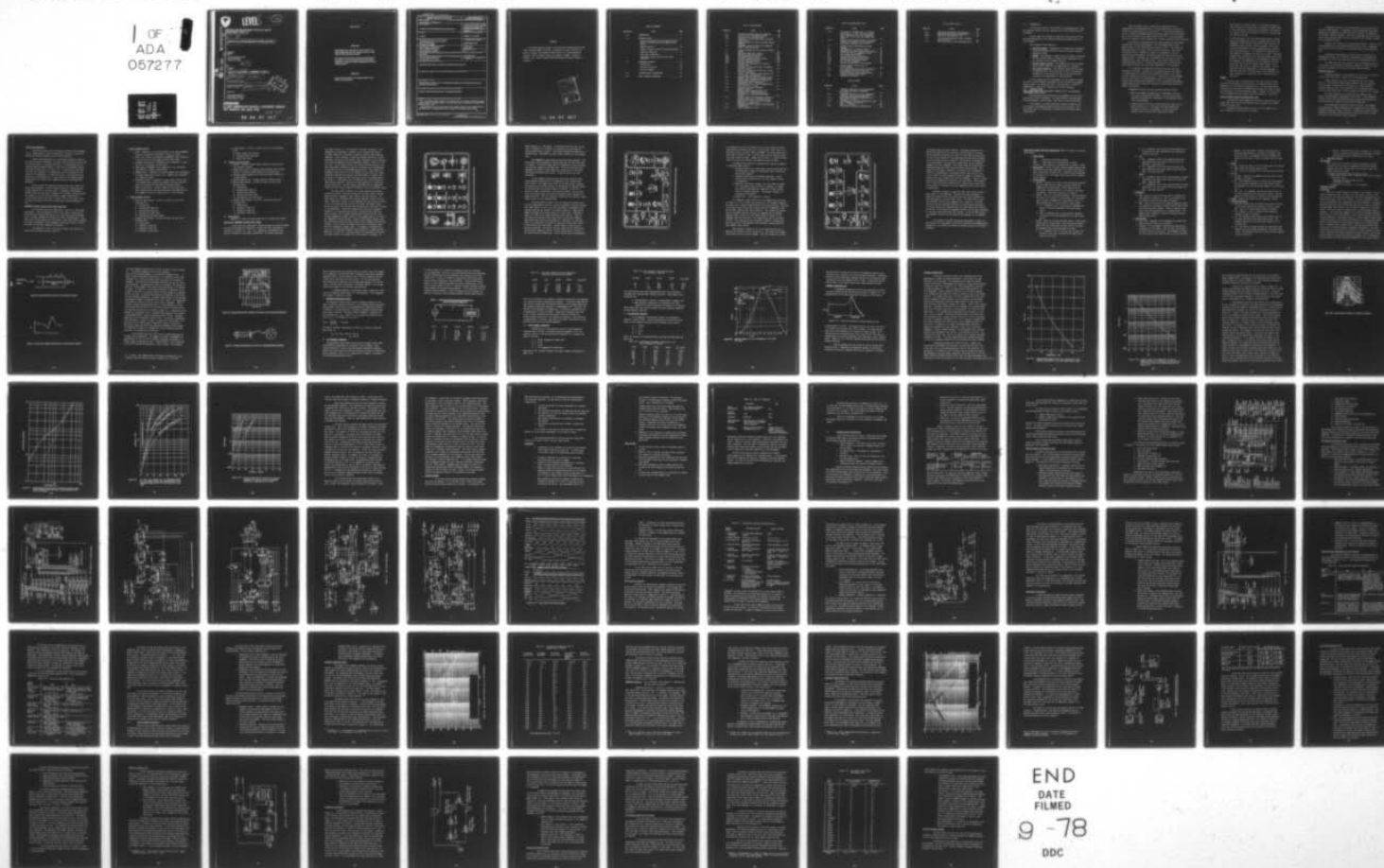
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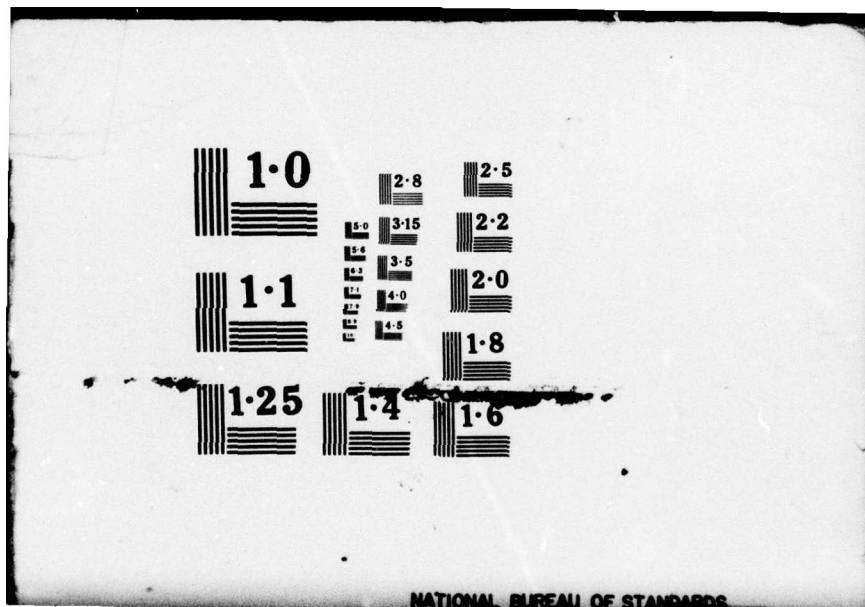
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RESEARCH AND DEVELOPMENT TECHNICAL REPORT

CORADCOM 77-0189-2-A

VEHICULAR INTERCOMMUNICATIONS SYSTEM.

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June 1978

Second Quarterly Report, ^{no. 2,} 1 Jan 1978 to 31 Mar 1978

ITT-A/OD-311A001-2

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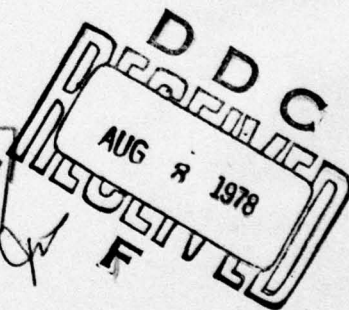
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1. REPORT NUMBER CORADCOM-77-0189-2-A ✓	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) VEHICULAR INTERCOMMUNICATIONS SYSTEM		5. TYPE OF REPORT & PERIOD COVERED SECOND QUARTERLY REPORT 1 JAN 78 to 31 MARCH 78
7. AUTHOR(s) J. HEITZ		6. PERFORMING ORG. REPORT NUMBER 311A001-2 ✓ <i>See Forward</i>
9. PERFORMING ORGANIZATION NAME AND ADDRESS ITT AEROSPACE/OPTICAL DIVISION 3700 E. Pontiac Street Fort Wayne, IN 46803 ✓ <i>3890000</i>		8. CONTRACT OR GRANT NUMBER(s) DAAB07-77-C-0189 ✓
11. CONTROLLING OFFICE NAME AND ADDRESS Project Manager, SINCGARS-V ATTN: DRCPM-GARS-LM Fort Monmouth, NJ 07703		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 694365.437.80.13.01
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Commander US Army Communications Research & Command Development ATTN: DRDCO-COM-RN-3 Fort Monmouth, NJ 07703		12. REPORT DATE APRIL 1978
		13. NUMBER OF PAGES 84
		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES CORADCOM-77-0189-2-B IS A CLASSIFIED APPENDIX TO THIS REPORT AND HAS LIMITED DISTRIBUTION		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Vehicular Intercom, Wireless Intercom, Voice Signal Multiplexing		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This is the Second Quarterly Report for the design study for a Vehicular Intercommunication System primarily for tracked vehicles. The report covers the time period from 1 January 1978 through 31 March 1978. Accomplishments for the period included final trade-off analysis for the, wireless intercom- munication system, and signaling techniques. Analysis of VOX systems is also included.		

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FOREWORD

This Second Quarterly Report on the Vehicular Communications System Study, Contract DAAB07-77-C-0189, is submitted 14 April 1978 for the period 1 January 1978 through 31 March 1978 by ITT Aerospace/Optical Division, 3700 E. Pontiac Street, Fort Wayne, IN 46803. Technical Monitor is Mr. Glenn Williman, DRDCO-COM-RN-3 | ITT-A/OD-Report Number is 311A001-2.

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TABLE OF CONTENTS

SECTION NO.	TITLE	PAGE
1.0	INTRODUCTION	1
2.0	INTERCOM SYSTEM.	1
	Radio System Operational Discrepancy Between AN/VIC-1 and Vehicular Intercommunications System	1
	TEMPEST Analyses	A1
	Logistic Support Analysis Considerations(LSA).	3
	Connector Selection.	4
	Front Panel Components	5
	Commander's Control Station Front Panel Trade-Offs	5
3.0	TECHNIQUES ANALYSIS.	18
	UHF Wireless	18
	Ultrasonic Wireless.	18
	Wireless Summary	37
4.0	INTERCOM SIGNAL DISTRIBUTION	41
5.0	AUDIO ACCESSORY INTERFACES	62

LIST OF ILLUSTRATIONS

FIGURE NO.	TITLE	PAGE
2-1	Present System Utilizing Two Connectors . . .	A2
2-2	Crew Station DC and Signal Routing	A3
2-3	DC Routing for Intercom System	A5
2-4	Commander's Control Panel with Individual Radio Control	9
2-5	Commanders Control Panel with Radio Control Combines	11
2-6	Commanders Control Station with Combined Radio & Intercom Control.	13
3-1	Antenna Configuration for External Wireless System	A9
3-2	UHF Narrow Band Block Diagram	A10
3-3	UHF Narrow Band Architecture.	A12
3-4A	Narrowband Wirless FM Case.	A16
3-4B	Internal Broadband Wirless FM Case.	A16
3-5A	External Narrowband FM Case	A18
3-5B	External Wideband FM Case	A18
3-6	Broadband FM Transceiver for Intercom Wireless User	A20
3-7	Broadband FM Transceiver Unit at Command Station Location.	A22
3-8	Equivalent Electrical Circuit for a Piezo- Electric Transducer	19
3-9	Typical Input Impedance Characteristics of a Piezo-Electric Transducer	19
3-10	Bandpass Characteristics Available from a Receiver and a Transmitter Characteristic . . .	21
3-11	Bending Mode Achieved by Two Discs in a Longitudinal Mode of Operation.	21
3-12	Measured Results of 2 LL-2 Transducers at a Far Field of ≈ 1 Inch	26
3-13	Receiving Transducer Frequency Response Curve.	27
3-14	Measured Sound Pressure Levels -VS- Frequency for a Tank Traveling 38 Miles/Hour on a Concrete Road (Rubber Treads)	29
3-15	Acoustic Power for Transmission Inside an Armored Vehicle for a S/N Ratio at the Receiver of 10 dB in a Noise Environment Equivalent to Figure 3-14	30
3-16	Frequency Selective Fading of an Ultrasonic Transmission.	32
3-17	Sound Attenuation in Air.	33

LIST OF ILLUSTRATIONS (Cont)

FIGURE NO.	TITLE	PAGE
3-18	Far Field -VS- Distance for 1) A Reverberant Room; 2) Free Field-Point Source Zero Attenuation Due to the Propagation Medium and 3) 50, 100, and 200 kHz Free Field	34
3-19	Acoustic Power Versus Distance for Several Frequencies Assuming 40 dB Environmental Noise with a Received S/N of 10 dB.	35
4-1	Baseband Signal Interconnection Block Diagram	45
4-2	TDM Components of Intercom System	47
4-3	Command Station TDM Timing Control Network.	48
4-4	Crew Station I/O at Commander Station	49
4-5	Crew Station TDM Network.	50
4-6	Crew Station Audio I/O Network.	51
4-7A	Command Station TDM Timing Diagram.	52
4-7B	Crew Station TDM Timing Diagram	52
4-8	MC-3418 CVSD Breadboard	56
4-9	SDM Voice Distribution Block Diagram.	59
5-1	Ambient Signal & Noise Levels at User Headphones	65
5-2	Noise Cancellation Microphone Performance	70
5-3	Environmental Noise Test Setup for Evaluating Noise Cancelling Microphone.	72
5-4	Adaptive Threshold VOX Network.	77
5-5	Radiometer VOX Network	79

LIST OF TABLES

TABLE NO.	TITLE	PAGE
3-I	Transducer Equivalent Circuit Bandwidth/Efficiency [Operated at Resonance (38.5 kHz)].	23
3-II	Transducer Equivalent Circuit Bandwidth/Efficiency Operated Below Resonance	24
3-III	High Frequency Bandwidth/Efficiency at f Resonance = 200 kHz	25
3-IV	Mid-Frequency Transducer Operation at, and Below, Resonance of 100 kHz	25
3-V	UHF -vs- Ultrasonic	40
3-VI	UHF Wireless Intercept Consideration.	A26

LIST OF TABLES (Cont)

TABLE NO.	TITLE	PAGE
4-I	CVSD Network Operating Characteristics . . .	54
4-II	TDM Versus SDM Technical Performance	60
4-III	TDM Versus SDM Component Cost	61
5-I	1/3 Octave and Spectral Level of Ambient Noise in M113A1	66
5-II	VOX Network Attack Time Performance Test . .	83

1.0 INTRODUCTION

In the second quarter of the Vehicular Intercommunications Study, the trade-off analysis has been completed and a baseline system can now be defined.

In this report the criteria are shown for the selection of Time Division Multiplexing as the signaling technique and UHF for the wireless intercom.

Also covered in this report are:

- 1 System Discrepancy: Explanation of an operational discrepancy discovered between the AN/VIC-1 and the Vehicular Intercommunication System.
- 2 TEMPEST: The planning of signal routing and power distribution for the intercom system is presented with advantages of the new intercom to aid in TEMPEST isolation.
- 3 Logistic Support Analysis: The progress made and the methods used to derive inputs for the GEMM program are reported.
- 4 Voice Channel Analysis: With improved intelligibility being an important goal, voice processing has been investigated to determine all areas within the scope of the intercom which contribute to an improvement in intelligibility.

To stay aligned with the requirements of the customer a meeting was held to discuss TEMPEST requirements for the Vehicular Intercommunications System. The meeting was held at ITT-A/OD with J. Prorock of CORADCOM and J. Heitz and J. McChesney of ITT-A/OD attending.

2.0 INTERCOM SYSTEM

RADIO SYSTEM OPERATIONAL DISCREPANCY BETWEEN AN/VIC-1 AND VEHICULAR INTERCOMMUNICATIONS SYSTEM

The functional specifications for the components of the intercom system have been established. The specifications were determined by the requirements of the contract, and study of the intercom usage.

A discrepancy of intercom capability between the AN/VIC-1 and the Vehicular Intercommunications System has been discovered. This occurs when there is a requirement to transmit on two separate radios simultaneously.

With the present AN/VIC-1 simultaneous transmission can be accomplished in the following manner. One crew member places the monitor switch on his 2298 control box in position "C". This gives him access to R/T "B". Another crew member places the monitor switch on his 2298 control box in the "A" position. This gives access to R/T "A". It is now possible for each to operate on their selected R/T's without interfering with each other.

The Vehicular Intercommunications System accomplishes simultaneous transmission in the following manner. One crew member positions his monitor switch to R/T-1 which gives him access to R/T-1. The second crew member positions his monitor switch to the R/T-2 position. This gives him access to R/T-2. However, to comply with Paragraph 3.3.1(a) of Specification DS-AF-0246A(A) the transmit audio must also be put in the intercom system. Therefore, the crew members hear each other as they are communicating on their individual radios. This can be a cause of confusion and possible error. (System intercom functions are described in first quarterly report, and front panel explanation in this report.)

It is important to understand the applications for which the intercom will be used. A majority of the intercom systems will operate in tracked vehicles in which the two transmitter problem is not likely to occur; however the possibility exists. Another use is in the command vehicle, where there is a high probability that two transmitters, and with the new intercom three transmitters, will be operated simultaneously. Careful analysis of the problem is required so that the best solution is found to the problem.

Recommended solutions and their good and bad points follow:

- 1 When a crew member is operating on a transmitter, gate out all audio to the operator's headset. This has the disadvantage that interruption of the operator in an emergency situation is not possible.
- 2 A modification of the first solution would be to gate off all audio to other R/T's. This would allow the intercom only information to pass to the headset. In this manner the operator could be alerted while operating his radio.

This requires a conscious effort of the operator giving the alert to switch to "intercom only" or operate his push-to-talk to the intercom only position to allow gating to the headset. i.e. this is similar to the AN/VIC-1 which will override when the intercom is keyed.

- 3 To take advantage of the two different applications (tracked vehicle and command post vehicle) a separate position on the commander's control monitor switch which would allow for uninterrupted radio operation could be provided. This could also be accomplished by internal programming which would be set during installation. It is difficult to determine the best approach to implement this mode at this time. This would separate radio information from intercom information and would eliminate intercom congestion in the command post application. This approach, if implemented from the commander's station front panel would give the operator added control, but requires more user ability to operate the equipment. If the additional mode was implemented by internal programming, operators would have to be made aware of the difference between a command post installation and a tracked vehicle installation.

SUMMARY

With the central switching used in the intercom audio routing, there are other probable options possible. The above solutions were presented as a cross-section of possibilities. The functional specifications for the Vehicular Intercommunications System will remain as they were presented in the first quarterly report. However, it is not difficult to implement variations should they be required at a later date.

LOGISTIC SUPPORT ANALYSIS CONSIDERATIONS (LSA)

The LSAM ADP Program (GEMM) was successfully exercised with the sample input data received from ECOM and results printed on our SYCOR terminal via phone line.

Government furnished LSAM input data for card numbers 22, 27, and 31 through 42 were received and reviewed.

Preliminary material lists were generated for the Time Division Multiplex (TDM) approach. The material lists were generated from preliminary block diagrams of the TDM system and will need to be updated as the system is further developed. The initial GEMM model run will not provide a highly accurate output however, the exercise will provide a format for later GEMM iterations.

Material cost estimates were obtained from vendors. Analysis of the priced material lists by Reliability/Maintainability led to replacement of initially selected connectors with equally reliable, less expensive ones.

Reliability/Maintainability analysis of MTBF and MTTR for the TDM approach indicate the 12,000 hour system MTBF using MIL-HDBK-217B procedures will not be met without some parts screening and/or burn-in.

All GEMM inputs have been generated for the TDM approach and we are presently in the process of obtaining a GEMM run. Results of this run will be provided in the first LSAM report (Data Item A004).

CONNECTOR SELECTION

Connectors presently in consideration by ITT-A/OD for the Intercom fall into three areas: signal, audio, and binding post.

Signal connectors are the type consistent with MIL-C-26482, Series I. This connector offers high reliability and will withstand the environment the intercom will be exposed to. These miniature circular connectors have a size consistent with the mounting area on the boxes with enough pins to keep the number of connectors at a minimum.

The audio connector is a standard six-pin connector which conforms to the performance requirements of MIL-C-5516. These connectors are mated with a twist-lock motion and have spring-loaded contacts for positive electrical connection with minimum voltage drop.

The binding posts selected are per MIL-P-55149, type PB08NA01 or an equivalent. These binding posts are designed for use in sealed equipment requiring external connections. Designed for vehicular units, these posts have heavy spring pressure to ensure good contact on small soft wire or heavy steel and copper conductors.

FRONT PANEL COMPONENTS

The prime criteria used for selection of control panel elements are, 1) rugged design, 2) ease of operation, 3) ability to survive in extreme environment conditions, and 4) high reliability.

Because sealing reliability is the hardest mechanical requirement for front panel components, two basic types of seals are to be used on the front panel; 1) rotating shaft seal, 2) flexible seal with no movement between sealing surfaces. These seals are preferable because they wipe the same area or no area at all. A third type of seal that ITT-A/OD could consider is a sliding seal, but this sliding seal has proven to be susceptible to a high failure rate. This failure is primarily due to contamination (i.e. dust, water) on the sliding surface. Foreign matter can either cause component failure or freezing of the mechanism.

Rotary switches and toggle switches best meet the criteria for front panel components. Rotary switches offering a rotating seal can be made rugged with a 0.250 inch shaft. In addition, when properly detented their position cannot accidentally be altered. Rotary switches are common to all users and are reliable. Toggle switches with a silicon rubber partial boot make a reliable, easy to use switch. With the metal bat exposed the switch can take abuse without breaking its seal.

COMMANDER'S CONTROL STATION FRONT PANEL TRADE-OFFS

The following section has three parts. Part one is front panel requirements. Part two presents several of the various iterations the front panel went through starting with one control per function proceeding to a logical combining of controls for a less cluttered panel. Part three gives a brief description of ITT-A/OD's latest front panel iteration. The control requirements of the commander's front panel (Part I) follows with parts two and three immediately thereafter.

The commander's control station front panel shall provide as a minimum the following operational features:

I - Radio Equipment Control

- 1 Power - capability to turn power ON/OFF to the three SINGARS-V radios as a group and the AN/PRC-77 radios as a group.
- 2 Power level control of transmitter (SINGARS-V only) capability to select any one of six power levels for each radio.
- 3 Frequency preset select (SINGARS-V only) capability to select any one of six presets for each radio.
- 4 ECCM control (SINGARS-V only) capability to set each radio individually to ECCM or Non-ECCM mode.
- 5 COMSEC Control - capability to set each COMSEC unit individually to either cipher text or plain text. COMSEC units controlled are VINSON and VANDAL.
- 6 Retransmit Control - capability to place radios two and three in retransmit mode allowing crew members to monitor and commander to transmit over and monitor retransmit radios.
- 7 Radio Access Control - provide capability to disable crew from transmitting on the radio and provide the capability for the commander to hear the radios only (i.e. crew silence).

II - Radio Equipment Control

- 1 Received Audio Control - be able to select any one of the following five:
 - a) Intercom only
 - b) Intercom plus radio one
 - c) Intercom plus radio two
 - d) Intercom plus radio three
 - e) Intercom plus all three radios
- 2 Transmit Audio Control - be able to select any one of the following four:
 - a) Intercom only
 - b) Intercom or radio one
 - c) Intercom or radio two
 - d) Intercom or radio three

3 Accent Control - be able to select any one of the following three:

- a) Radio louder than intercom
- b) Intercom louder than radio
- c) Equal audio levels

III - External Station Control

- 1 Disable - external station cannot transmit or receiver over the intercom or radios.
- 2 Request for access to intercom system generated from external station to be shown on front panel by a flashing light.
- 3 External station enabled to use intercom system indicated by a light being on.
- 4 External Station Call - flashes light at external station.
- 5 Receive Audio Control - be able to select any one of the following five:
 - a) Intercom only
 - b) Intercom plus radio one
 - c) Intercom plus radio two
 - d) Intercom plus radio three
 - e) Intercom plus all three radios
- 6 Transmit Audio Control - be able to select any one of the following four:
 - a) Intercom only
 - b) Intercom or radio one
 - c) Intercom or radio two
 - d) Intercom or radio three

IV - Power Control

Capability to turn on intercom power only or intercom plus radios

ANALYSIS OF COMMANDER'S STATION FRONT PANELS

In the layout of a front panel, attention should be called to proper selection of switches and indicators. Factors that were considered in selection of controls are: size, cost, ruggedness, environmental suitability, reliability, and product availability. Of primary importance

were human factors (i.e. the interface of soldier to machine). This encompasses the following: operation of the intercom with winter clothing, operation of intercom in different ambient light conditions (darkness), covert operation, minimizing erroneous operation or interpretation, user skills and attitudes, habit inference or cross training from previous generation intercom equipment (AN/VIC-1) which will still be in use. The following section will briefly describe several of the many front panels considered along with the benefits and disadvantages of each panel based on the aforementioned factors. The inclusion of SINCGARS-V radio controls into the commander's front panel will figure prominently because of the greatly increased number of controls that will have to be added and still physically reside in the same space as the AN/VIC-1. Three panels will be presented with the last being the latest design iteration. Each has the same capability to control the intercom and radios. The front panels presented give the commander's station the full control capability defined in the first quarterly report.

The front panel of Figure 2-4 has four separate and distinct sections of control. The four sections are DC power control, external station control, commander's audio control, and radio control. The front panel to be considered first provides separate controls for each radio. Referring to Figure 2-4 and examining the radio control section, it will be noticed that each of the three radios has separate push-buttons to control the four functions associated with each radio (a total of 12 pushbuttons). Electronic displays were chosen over mechanical displays (i.e. 6-position rotary switch, Digitran Series 12000 mini-button switches, etc.) because the mechanical displays did not allow the main commander's control station to view changes made by the auxiliary commander's control station. Present system design concepts allow for simultaneous display of radio status at both commander and auxiliary stations. Either station can change radio status by pressing a push-button to increment or toggle states. In changing to electronic displays the only additional hardware required would be 7 segment drivers. Operation is as follows: Pushing a preset select pushbutton will cause the preset channel to increment each time the button is pushed. RF

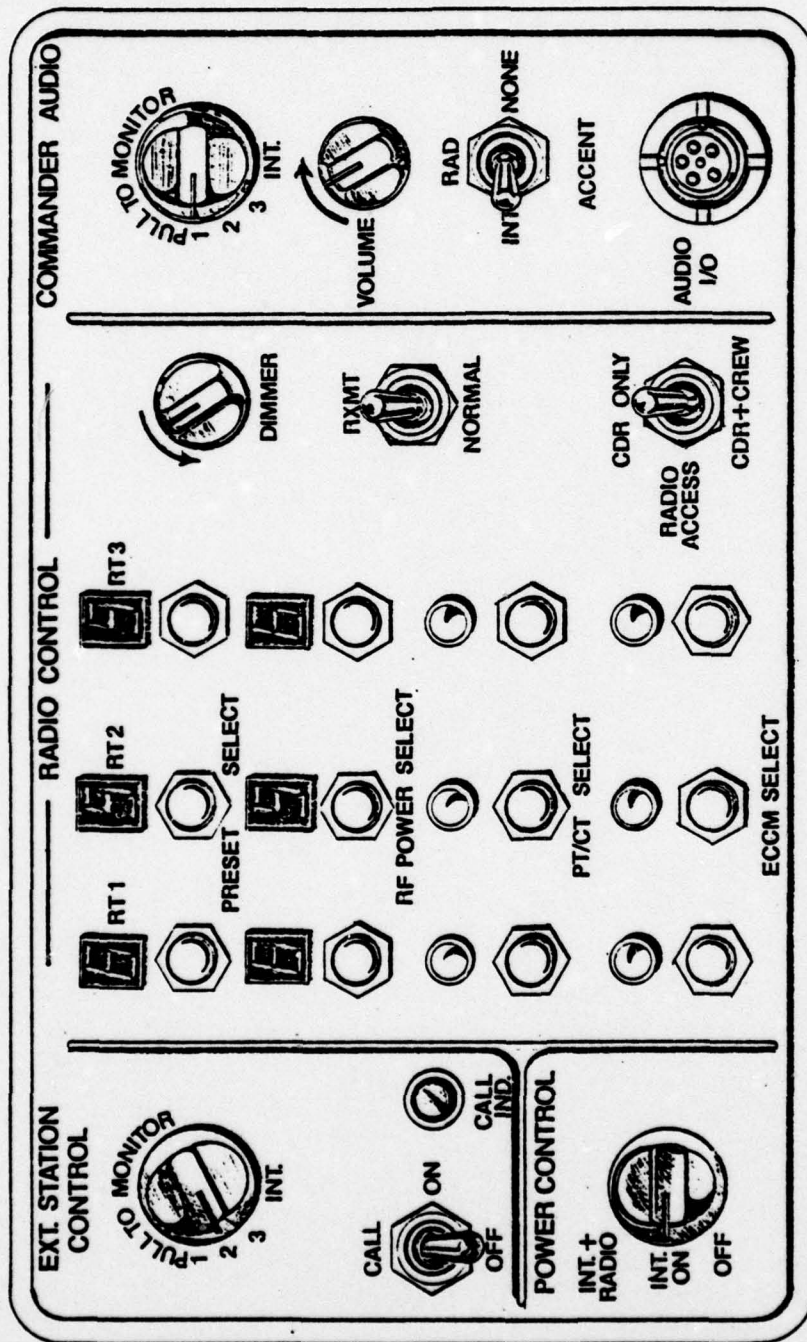


Figure 2-4. Commander's Control Panel with Individual Radio Control

power operates in a like manner. For ECCM and PT/CT the state of the radio is toggled (i.e. ECCM goes to non-ECCM and upon pressing the button again returns to ECCM). This design incorporates pushbuttons to minimize space. Retransmit and radio access switches are self explanatory.

The commander's audio control section has three switches. The audio select switch determines received audio and the radio over which to transmit. With switch pushed down the commander will hear one radio only and will transmit on the same radio. With switch pulled up the commander will hear all three radios and transmit only on the radio selected by the audio select switch. Volume and accent are self-explanatory.

In the external station control section the auxiliary select switch operates identically as the commander's audio control audio select switch. The toggle switch, when in the OFF position, disables the external station from receiving or transmitting to intercom system. In the ON position the external station is enabled. In the CALL position a light is activated at the external station. The call indicator on the front panel is on with the external station enabled (i.e. toggle switch ON). The call indicator flashes when the external station desires access to the intercom system.

The front panel of Figure 2-4 can be improved in several ways. The first improvement would be to reduce the number of switches involved with radio control so as to allow for replacement of pushbuttons with switches which are not subject to accidental operation. Reducing the number of displays and switches would also lower costs. Referring to Figure 2-5, there is no longer individual radio controls. There is only one set of controls with a radio select switch which signifies which radio these controls are attached to. Operation is as follows: radio to be controlled is selected by turning the radio select switch in the center of the front panel. Current status of radio is automatically displayed. The preset, RF power, ECCM, and CT switches are bi-directional momentary switches that are spring loaded to return to the center position automatically. Preset and RF power are decremented

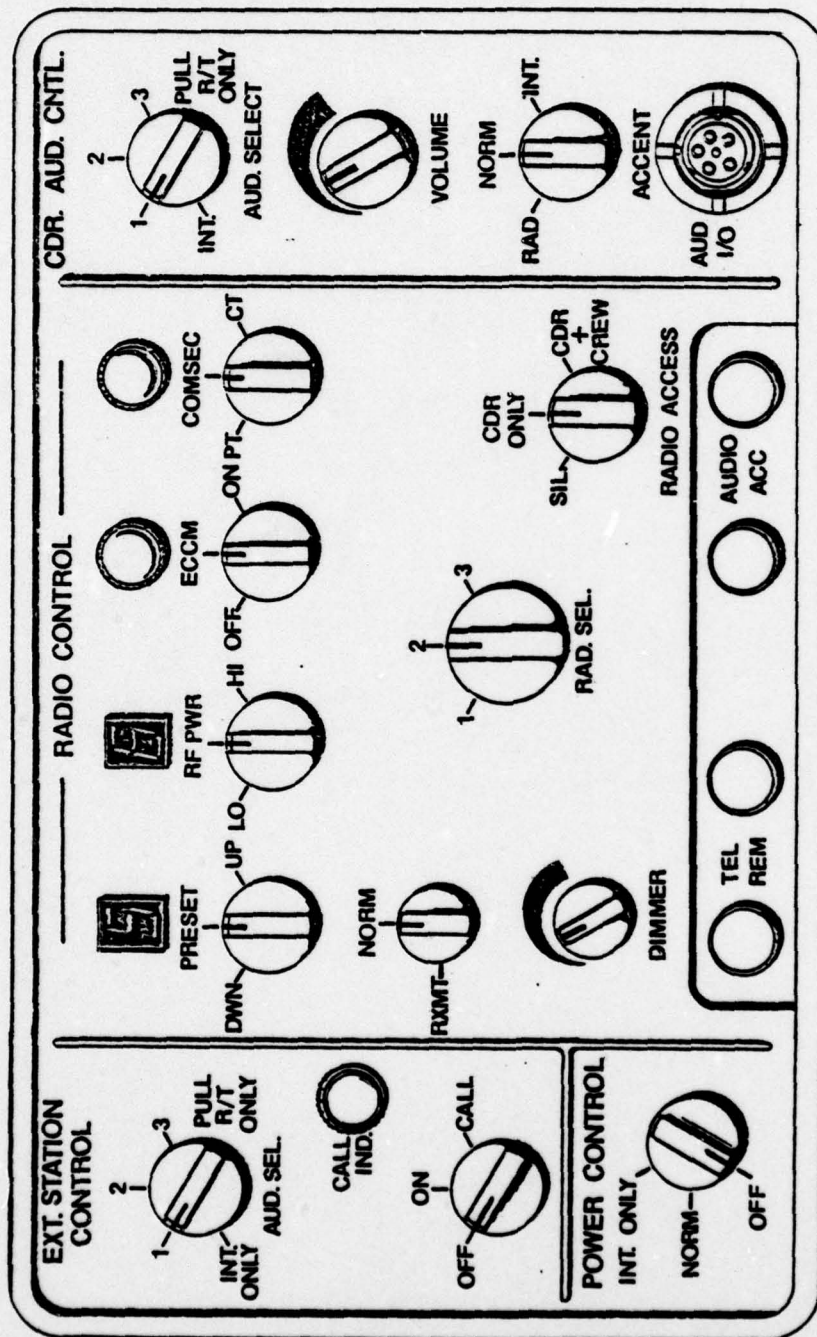


Figure 2-5. Commanders Control Panel with Radio Control Combined

or incremented once for each separate twist of the respective switch. Normal power up sequence would be to turn the radio select switch to 1 and adjust preset, RF power, ECCM, and COMSEC. The radio select switch would then be turned to radio 2 and the radio would be adjusted using the status control switches. Repeat this for radio 3. After the three radios are set up the intercom crew members can use the radio.

To summarize the benefits of combined radio control as opposed to individual radio control:

- Increased Control for a Given Space - preset and RF power are bi-directional as opposed to individual radio controls uni-directional operation.
- Decreased Possibility of Accidental Operation - rotary switches when accidentally hit will not trigger as easily as pushbuttons.
- Operation with Winter Clothing - the front panel of Figure 2-4 would require rotary switches to replace, or a guard cast around the pushbuttons. Operation of radio controls would be extremely difficult. The design of Figure 2-5 eliminates this problem.
- Reduced Cost - less assemblies to install.

The commander's audio control was also changed from that shown in Figure 2-4 so as to reduce the possibilities of accidental operation. The result was to replace toggle switches with rotary switches. Functions of the audio select switch were reversed from PULL TO MONITOR to PULL FOR R/T ONLY (receives only radio selected). This reduced the seriousness of accidental operation in that the commander upon accidental operation would listen to all the radios whereas in Figure 2-4 the commander would not realize he is no longer monitoring his auxiliary receiver. The external station was modified likewise. Binding posts were now possible to add because of the decreased crowding resulting from combined radio control.

Upon referring to Figure 2-6 it will be realized that this is basically an optimized version of Figure 2-5. Other than the reorganization there are only two main changes. The first change was to remove

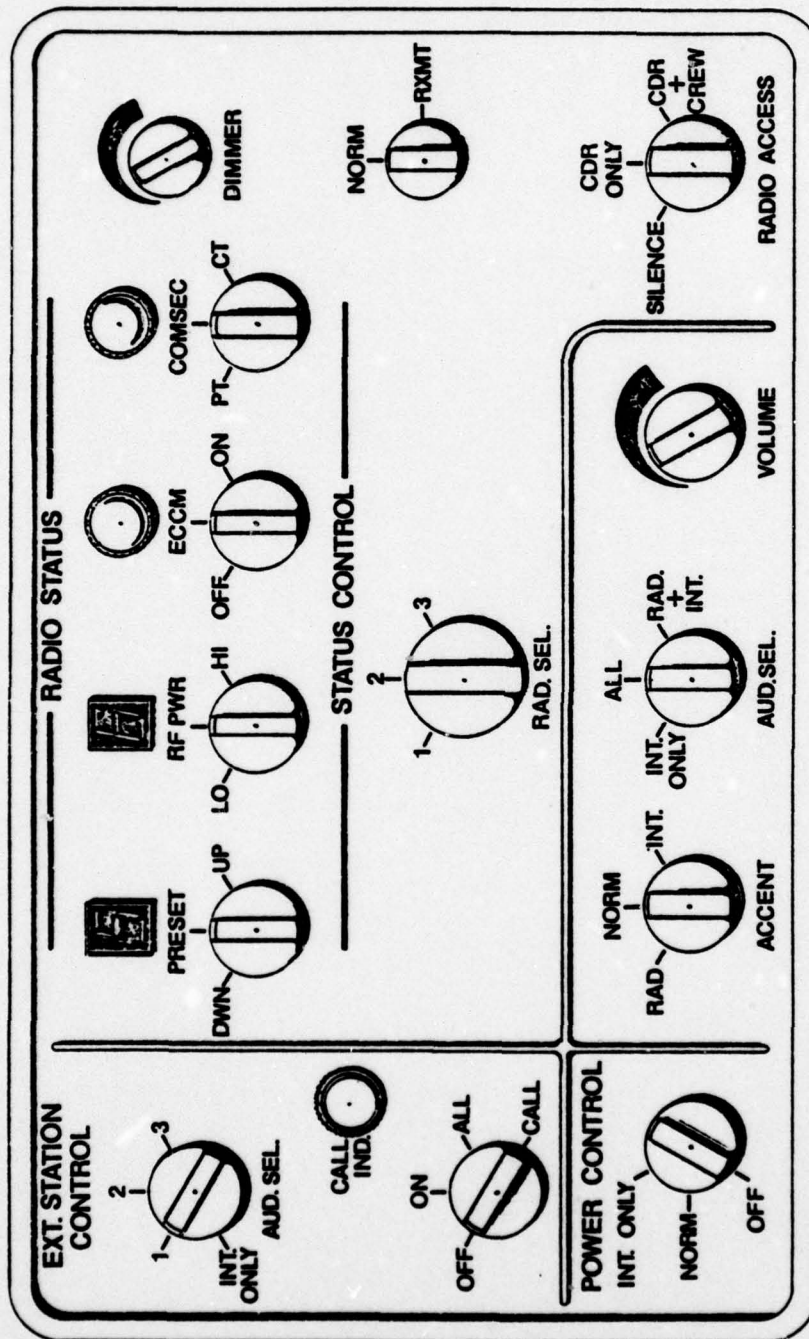


Figure 2-6. Commanders Control Station with Combined Radio & Intercom Control

the binding posts and audio connector. The primary influence in removing the connectors was to unclutter the front panel so it would not be confusing to the new user and it was felt that the audio cable as well as wire connected to the binding posts would obscure displays as well as hinder access to controls. The inclusion of binding posts on the front panel is not necessary because they are not frequently changed by the tank commander. The second change was reallocation of functions between the radio select and audio select switches. The reason for the change is because it is possible for the commander to think he is transmitting on a different preset, power level or etc. as of a result of having separate switches in Figure 2-5 controlling display select and transmit select for the commander. Figure 2-6 eliminates this by combining the functions onto one switch. The push-pull type of switch may now be replaced with a simpler rotary switch which is not subject to freezing at sub-zero temperatures and is less costly to manufacture.

Referring to Figure 2-6 again the radio select switch controls which radio is to be displayed. Naturally the radio displayed is modified by status control and hence the status control modified the radio specified by the radio select switch. The radio select switch also specified the radio the commander will transmit on. The audio select switch has the primary function of controlling received audio. In the ALL position the commander hears all three radios plus intercom. In the RAD + INT position the commander receives only the radio specified by the radio select switch plus the intercom. In the INT ONLY position the commander receives only the intercom and transmits to crew members only.

In conclusion, ITT-A/OD believes the front panel of Figure 2-6 best fulfills the requirements of the Army's Vehicular Intercommunication System but is by no means not subject to further revisions as the study progresses.

FRONT PANEL CONTROL FUNCTIONS DESCRIPTIONS (Refer to Figure 2-6 for front panel layout)

1 POWER CONTROL

- OFF - No power to intercom or radios
- NORM - Power supplied to intercom and all radios
- INT ONLY - Power supplied to intercom only, no power to radios

2 RADIO STATUS - Preset, RF power, ECCM and COMSEC displays show the status of the radio specified by the radio select switch. When in ECCM mode the light is ON. Likewise when transmitting CT the light is ON. The dimmer switch controls the intensity of the displays.

3 STATUS CONTROL

- a. RAD SEL - specifies the radio to be displayed and specifies the radio upon which the preset, RF power, ECCM, and COMSEC switches operate upon. These switches are bi-directional, spring-loaded so as to return to the center up position. The center up position is inactive.
- b. PRESET - There are six possible presets. When incrementing the preset it is possible to loop around (i.e. upon reaching 6, one more increment will cause preset to go to 1). When decrementing it is also possible to loop around.
 - 1) UP - A momentary turn to this position increments the preset of the radio specified by the radio select switch.
 - 2) DOWN - A momentary turn to this position decrements the preset of the radio specified by the radio select switch.
- c. RF PWR - There are six possible power levels. The RF power display does not loop around. Upon reaching the highest power level the counter does not turn over to the lowest. The commander must instead decrement six times.
 - 1) HI - A momentary turn to this position increases the RF power of the radio specified by the radio select switch by one level.

- 2) LO - A momentary turn to this position decreases the RF power of the radio specified by the radio select switch by one level.

d. ECCM

- 1) OFF - A momentary turn to this position places the radio specified by the radio select switch out of ECCM mode. Light goes OFF.
- 2) ON - A momentary turn to this position places the radio specified by the radio select switch into ECCM mode. The light turns ON.

e. COMSEC

- 1) PT - A momentary turn to this position places the radio specified by the radio select switch into plain text mode. Light goes OFF.
- 2) CT - A momentary turn to this position places the radio specified by the radio select switch into cipher text mode. The light turns ON.

4 RETRANSMIT

- a. NORM - Radio two and three may be used by commander and crew members to transmit on. Only in this position can the status of radios two and three be changed.
- b. RXMT - Radios two and three are connected together through the intercom for retransmit on presets and RF power levels selected using status control. Status of radios two and three cannot be modified while in retransmit mode. Crew members cannot transmit on radios two and three but may monitor these radios.

5 RADIO ACCESS

- a. CDR + CREW - Commander and crew members may transmit and monitor radios as well as use intercom.
- b. CDR ONLY - The crew member's stations are disabled from transmitting on the radios. The crew still can listen to the radios and use the intercom. The commander can transmit and receive on the radios as well as use the intercom.

- c. SILENCE - The crew member's stations are entirely disabled from transmitting on the radios or intercom. They can only listen. The commander can still transmit and receive over the radio as well as transmit over the intercom.

6 ACCENT

- a. RAD - Accent the radio so as to be louder than the intercom.
- b. NORM - Radio and intercom equally loud.
- c. INT - Accent the intercom so as to be louder than the radio

7 AUD SEL

- a. INT ONLY - Disables the commander from receiving or transmitting on the radios.
- b. ALL - The commander receives all three radios and transmits only on the radio specified by the radio select switch. The commander will receive and may transmit on the intercom also.
- c. RAD + INT - The commander receives and transmits only on the radio specified by the radio select switch. The commander will receive and may transmit on the intercom also.

8 VOLUME - Adjusts the loudness of the commander's headset.

9 EXT STATION CONTROL

- a. CALL IND - Flashes when an external user presses the push-to-talk button provided the external station is turned OFF. Light is ON when external station is enabled.
- b. OFF - External station is disabled from listening or talking to radios or intercom.
- c. ON - The external station receives and transmits only on the radio specified by the audio select switch. The external station will receive and may transmit on the intercom also.
- d. ALL - The external station receives all three radios and transmits only on the radio specified by the audio select switch. The external station will receive and may transmit on the intercom also.

- e. AUD SEL - Specifies which radio to transmit on. Also provides the intercom only function which disables the station from receiving or transmitting on the radios.

3.0 TECHNIQUES ANALYSIS

UHF WIRELESS

UHF - During the last quarter the UHF investigation has been carried out in the areas of interference from other onboard equipment and types of UHF systems which could be used. This report on UHF will include:

- Expected interference from VHF radios (RT-524)
- Systems which could be used to implement UHF wireless intercom
 - Narrowband system
 - Compliant with MIL-STD-188C and 461A
 - Non-compliant system
 - Wideband (by its nature it is non-compliant)

ULTRASONIC WIRELESS

Transducers:

There are a limited number of transducers that operate in the ultrasonic frequency range. Of these, the piezo electric crystal is the best choice for the intercom application. The other transducers are the whistles and sirens, the use of a flame or electric discharge, a capacitance type transducer and a magnetostrictive type transducer. The whistle type and flame type cannot be modulated and cannot be used as a receiver. The capacitance type requires a bias voltage if linearity is to be maintained. The piezo electric transducer has a very high dynamic range of operation. It is relatively rugged and by choosing the proper material is easily driven by solid state devices. Of the various materials available, the most promising is the barium titanate or lead zirconate titanate. Both of these materials can be driven with relatively low voltage while quartz which is a good material in many respects requires a very high voltage drive. Materials such as Rochelle Salt, which has many desirable characteristics are highly affected by temperature and humidity. The equivalent circuit of a piezo electric transducer is shown in Figure 3-8. This circuit represents the normal transmitting circuit; however, the receiver circuit results by replacing the acoustic impedance, R_c , by a generator and connecting the voltage measuring preamplifier at the input terminals.

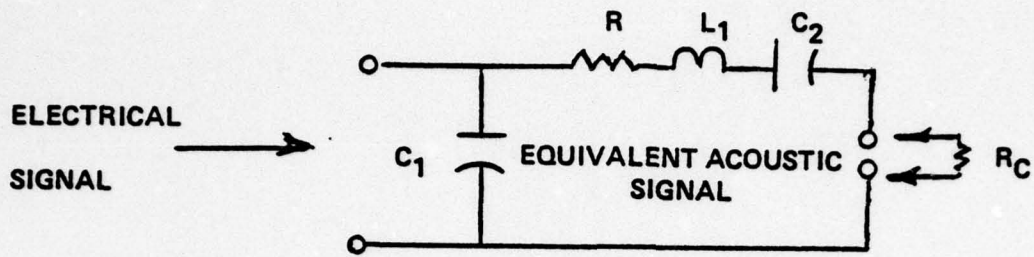


Figure 3-8. Equivalent Electrical Circuit for a Piezo-Electric Transducer

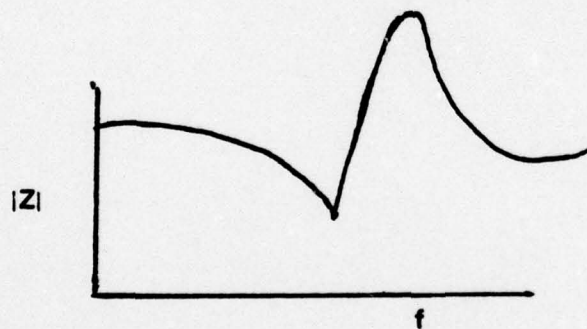


Figure 3-9. Typical Input Impedance Characteristics of a Piezo-Electric Transducer

The input impedance characteristic of such a device is shown in Figure 3.9. The minimum impedance is the series resonance point and the maximum impedance is the parallel resonance point. In order to obtain reasonable efficiencies, it is necessary to drive the transducer at its series resonance point and receive on the parallel resonance. The efficiency of transducers used this way has not as yet been determined. One manufacturer states an efficiency of 5 percent is good, but various papers on the subject give efficiencies of 15 percent or higher. In order for a conservative estimate, an efficiency of conversion of electrical to acoustic energy has been assumed to be approximately 10 percent. By having the receiver and transmitter crystal with the same resonant frequencies, a bandpass characteristic can be achieved which appears capable of bandwidths of at least 4 kHz at low frequencies and probably as high as 12 kHz at 100 kHz carrier frequency. GTE¹ developed a cordless telephone which had a 3.7 kHz bandwidth at 23 kHz using transducers that are used in the control units of television sets. The bandwidth characteristic is shown in Figure 3-10. Transducers can be operated in longitudinal mode or thickness mode assuming x-cut crystals. A longitudinal mode is used for frequencies below 100 kHz. Thickness modes are used for frequencies above 100 kHz. By using two longitudinal mode transducers, circular in shape, in opposition to each other, it is possible to get a bending mode of operation as shown in Figure 3-11. This mode of operation gives wide propagation beamwidth (if the number of transducers are kept to a minimum for a given transmitter/receiver operation, wide beamwidths are necessary).

The thickness mode which can be used at high frequencies has extremely narrow beamwidths. For example, at 60 kHz, the beamwidth is approximately 13° for one inch in diameter transducer (thickness is 1.5 inches, making an impractical size). Thickness mode is also termed the "piston mode" because the transducer is like a piston. The thickness

¹ R. K. Stevens, Said Communication by Ultrasonic Transmission in Air, Automatic Electric Technical Journal, October 1970, p. 182-188.

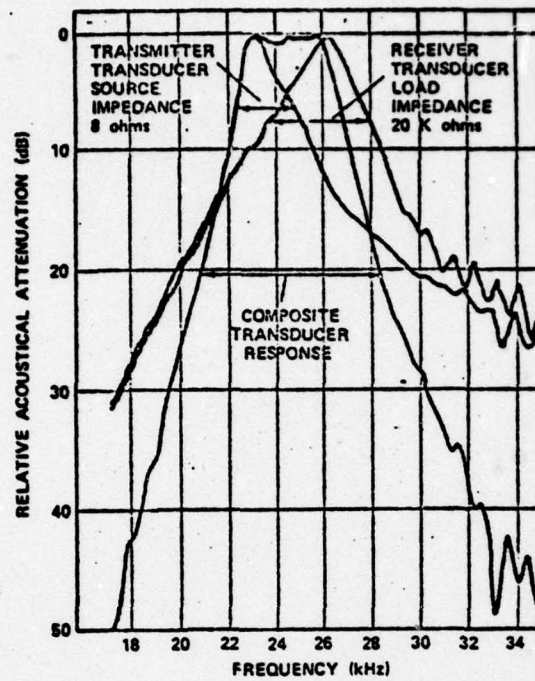


Figure 3-10. Bandpass Characteristics Available from a Receiver and a Transmitter Characteristic

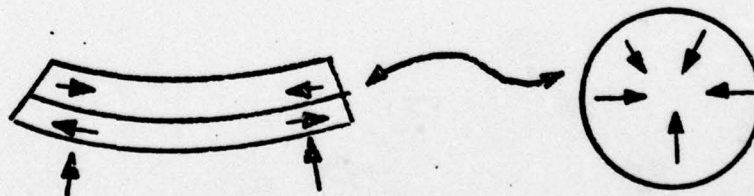


Figure 3-11. Bending Mode Achieved by Two Discs in a Longitudinal Mode of Operation

mode of operation has the advantage that the crystal can be very rugged in its mounting. The flexural type of operation which gives reasonable beamwidth tends to be more fragile since it must be supported and the crystal has to move about the pivot points. For the type operation envisioned with the Intercom, the flexural mode appears to be the best choice. Further study is necessary to determine whether it can be made sufficiently rugged to meet military specifications.

A transducer analysis was performed using a "Linden Lab" ultrasonic air transducer Model 70120, as a starting point. This transducer was designed to operate at 40 kHz.

I - TRANSDUCER EQUIVALENT CIRCUIT

The equivalent circuit of an acoustic transducer analyzed in this study is shown in Figure 3-8 where C_1 is the transducer plate capacitance whose nominal value is given in the manufacturer's specification sheet as 3000 pf. R is the electrical to acoustic interface resistance whose value shall be derived. The device series resonance is specified as 38.5 kHz where $X_{L1} = X_{L2}$. Thus $Z_{in} = X_{C1}/R$ where Z_{in} is given as 340 ohms and $X_{C1} = -j 1378$ ohms at 38.5 kHz.

$$\text{Then } R = \frac{Z_{in} X_{C1}}{X_{C1} - Z_{in}} = 330 \text{ ohms}$$

At parallel resonance (specified at 40 kHz) Z_{in} is given as 7000-ohms which leads to:

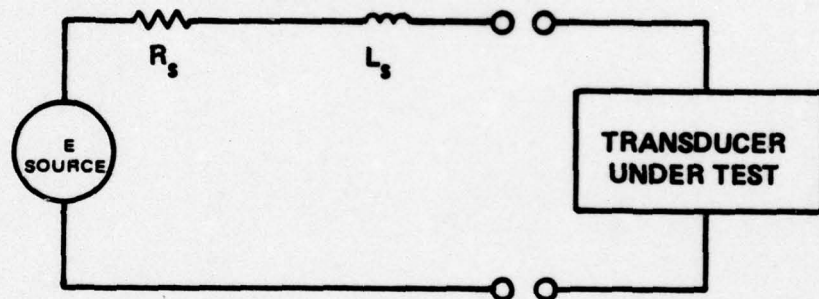
$$\begin{aligned} X_{L1} - X_{C2} &= X_{C1} \quad \text{then } L_1 = 93 \text{ mh} \\ C_2 &= 182 \text{ pf} \end{aligned}$$

II - LOW FREQUENCY OPERATION

The equivalent circuit model was utilized to identify device bandwidth/efficiency parameters as a function of input loading. Input loading consisted of a series resistor-inductor combination connected between the voltage source and the device input as a means of controlling device bandwidth. Table 3-I is a compilation of computer calculations of the following equivalent circuit.

As noted in Table 3-I, loading the transducer input with different R_s - L_s combinations results in a spectrum ranging from narrow bandwidths and good efficiencies to broad bandwidths with subsequent poor transmission loss. A point is reached in loading where worse efficiencies do not result in substantial wider bandwidths. System specifications demand a 12 kHz communication bandwidth (double sideband about 6 kHz), thus the results shown in Table 3-I indicate resonant frequency operation cannot support the necessary wide bandwidth. It has been noted that the receiver transfer function is flat at frequencies below resonance and peaking at resonance, hence broadband operation should become feasible.

**Table 3-I. Transducer Equivalent Circuit Bandwidth/Efficiency
(Operated at Resonance (38.5 kHz))**



R_s (Ω)	L_s (mh)	f_o (kHz)	Δf (kHz)	E_o/E_{in} (dB)
0	0	38.647	566	0
71	3	37.682	930	+ 0.42
21	3	37.648	637	+ 3.0
238	3	37.761	1600	- 5.14
714	3	38.5	3000	-11.5
1428	3	39.45	3100	-14.5

Table 3-II. Transducer Equivalent Circuit Bandwidth/
Efficiency Operated Below Resonance

L_s (mh)	R_s (Ω)	f_o (kHz)	Δf (kHz)	E_o/E_{in} (dB)
16.2	0.01	23.66	40	+19
16.2	21	23.66	220	+ 2.9
16.2	71	23.68	686	- 6.7
16.2	200	23.78	1930	-15.4
16.2	400	23.83	3950	-21.35

Table 3-II illustrates the transducer bandwidth/transmission loss properties as a function of input loading below resonance. At resistive loads greater than several hundred ohms the bandwidth doubles as the loading doubles and the transducer efficiency decreases a corresponding 6 dB. To achieve the desired 12 kHz bandwidth if AM modulation is selected a transmission loss of approximately 30 dB would result. Manufacture transducer data indicates a further efficiency decrease results from the electrical to acoustic energy conversion at the ceramic/air interface. This efficiency is approximately 10 percent, resulting in an overall transmission loss of greater than 50 dB at the desired bandwidth.

III - HIGH FREQUENCY OPERATION

Extrapolation of the equivalent circuit to high frequencies (resonance above 100 kHz), by assuming constant impedances at all frequencies, results in the following circuit parameters at a resonant frequency of 200 kHz.

$$\begin{aligned}
 C_1 &= 500 \text{ Pf (supplied by Linden Lab)} \\
 C_2 &= 36 \text{ Pf} \\
 L_1 &= 18 \text{ mh} \\
 R &= 1K \Omega \text{ (supplied by Linden Lab)}
 \end{aligned}$$

Operation at this resonant frequency with input loading is tabulated in Table 3-III.

Table 3-III. High Frequency Bandwidth/Efficiency
at f Resonance = 200 kHz

R_s (ohms)	L_s (mh)	f_o (kHz)	Δf (kHz)	E_o/E_{in} (dB)
0	0	198	8.8	-0.03
500	0	198.1	14.8	-3.6
0	0.5	193.1	8.5	+4.0
0	1.56	163	2.0	+14

The resulting data shows good bandwidth/efficiency when operated at resonance and a 500-ohm input loading resistance. Other factors to be considered are:

- The beam angle at 200 kHz is approximately 3 degrees, and
- High frequency transducers are constructed such that operation in a high vibrational environment is ill-advised.

These factors more than offset the good electrical qualities exhibited by high frequency operation.

IV - MID-FREQUENCY OPERATION

As a compromise, investigation shifted to mid-frequency operation, namely 100 kHz. Again extrapolating the equivalent circuit values to this frequency resulted in the following circuit values:

$$\begin{aligned}
 C_1 &= 1000 \text{ Pf} \\
 C_2 &= 73 \text{ Pf} \\
 L_1 &= 37 \text{ mh} \\
 R &= 33\Omega
 \end{aligned}$$

Table 3-IV contains the accumulated data resulting from additional computer runs.

Table 3-IV. Mid-Frequency Transducer Operation at, and Below, Resonance of 100 kHz

R_s (Ω)	L_s (mh)	f_o (kHz)	Δf (kHz)	E_o/E_{in} (dB)
0	0	96.85	1.4	- 0.003
280	0	97.0	2.5	- 5.3
500	0	97.0	2.5	- 8.0
280	3	83.4	- -	-12.5
200	3	82.9	8.5	- 9.9
100	3	82.0	4.2	- 4.5
0	3	82.0	<0.1	+12.8
0	4	73	<0.1	+15
280	4	74.3	10.7	-15.4

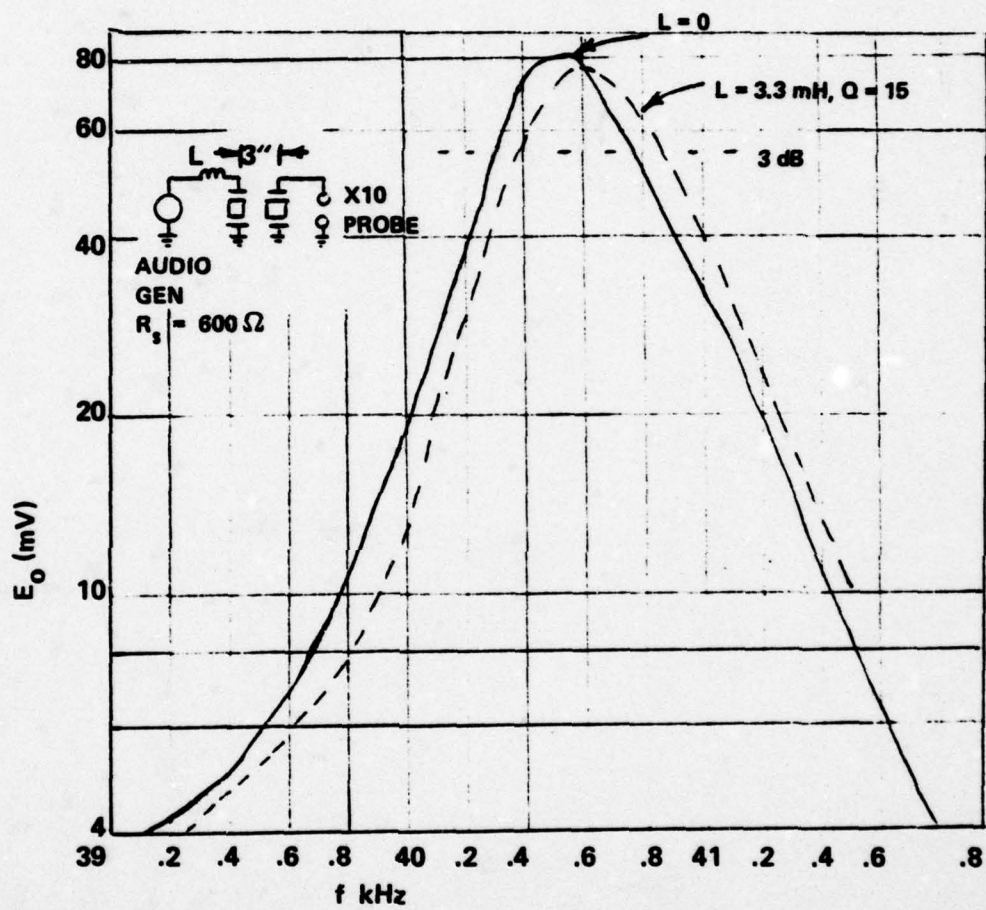


Figure 3-12 Measured Results of 2 LL-2 Transducers at a Far Field of ≈ 1 Inch

The data tends to follow the trend of wide bandwidth leading to poor efficiencies at, and below, the 100 kHz resonant frequency. Additional factors include a beam angle somewhere between the low frequency model (30 deg) and the high frequency device (3 deg). Vibrational environments should not be a major problem when operating below 100 kHz.

MEASURED TRANSDUCER DATA

A transducer transmitter-receiver pair operating at 40 kHz was bench tested with the resultant data plotted in Figure 3-12. The measured data on the Linden Lab models was taken at a far field of

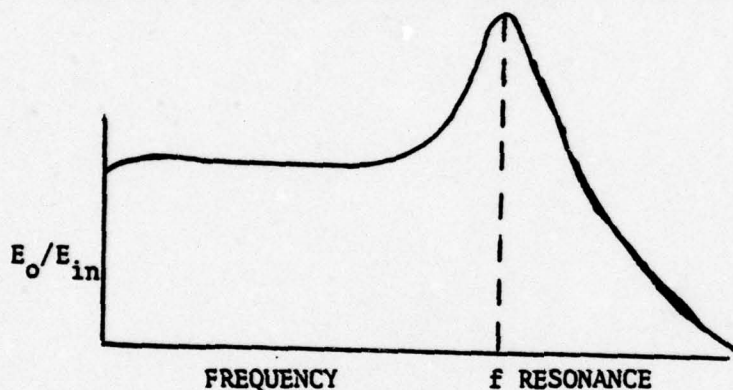


Figure 3-13. Receiving Transducer Frequency Response Curve

10 wavelengths (3 inches). The figure reflects two curves, one with a 3.3 mh input load and the other with no loading. The resulting data shows very little difference as a function of input loading. This contradiction with calculated data arises from the fact that both the transmitting and receiving transducers were operating at their resonant peaks. Figure 3-13 is a receiver response curve depicting the receiver transfer function.

From the response plot the reason for the no loading effect becomes obvious. Regardless of transmitter loading, the receiving transducer dictates the bandwidth when both are operated at resonance.

SYSTEMS CONSIDERATIONS:

Inside of the armored vehicle, the transducers must cover approximately a sphere although reverberation should allow for some dead spots in the coverage. The background noise inside the armored vehicle is very high. Measurements were taken on a German tank traveling 38 miles per hour over a concrete road. The background noise spectrum is shown in Figure 3-14. This is a power density spectrum based on a 6 kHz bandwidth. Data on American vehicles is not available; however, it is assumed that the noise data would be similar to that of the German vehicles. If a signal noise ratio of 10 dB is assumed and if the transducer is assumed to radiate equally in all directions, and if maximum distance of transmission inside the armored vehicle is five feet, the power frequency curve shown in Figure 3-15 results. Power is the acoustic power out. Assuming an efficiency of the transducer of 10 percent means that all of the power values have to be multiplied by 10 for electrical power input. It is assumed that the maximum electrical power is 1 watt. This is for two reasons: possible deleterious effect on personnel and the total power drain. Using an acoustic power of 0.1 watt, a frequency of 60 kHz is obtained from Figure 3-15. It is, therefore, proposed that the carrier frequency be 60 kHz and that single sideband operation be used since it is difficult to achieve the widebandwidth necessary to support the sidebands if double sideband is used. With 6 kHz audio bandwidth, a double sideband requires a 12 kHz bandwidth which although feasible with transducers over 100 kHz, is not feasible at 60 kHz. Preliminary study shows that 6 kHz can be achieved with a properly designed transducer at 60 kHz. If carrier suppressed double sideband modulation is used, the transducer characteristic can eliminate the lower sideband.

Multipath problems exist inside the tank. Normally in a reverberation environment the multipath is so high that the small variations that occur in the spectrum produce little or no distortion. Unfortunately, at frequencies such as 60 kHz, the air attenuation reduces the multipath to the point where significant variations occur in the frequency spectrum. Standard Elektrik Lorenz (SEL) has made measurements that indicated at 70 kHz the distortion of 10 to 20% can exist. The experience of GTE in

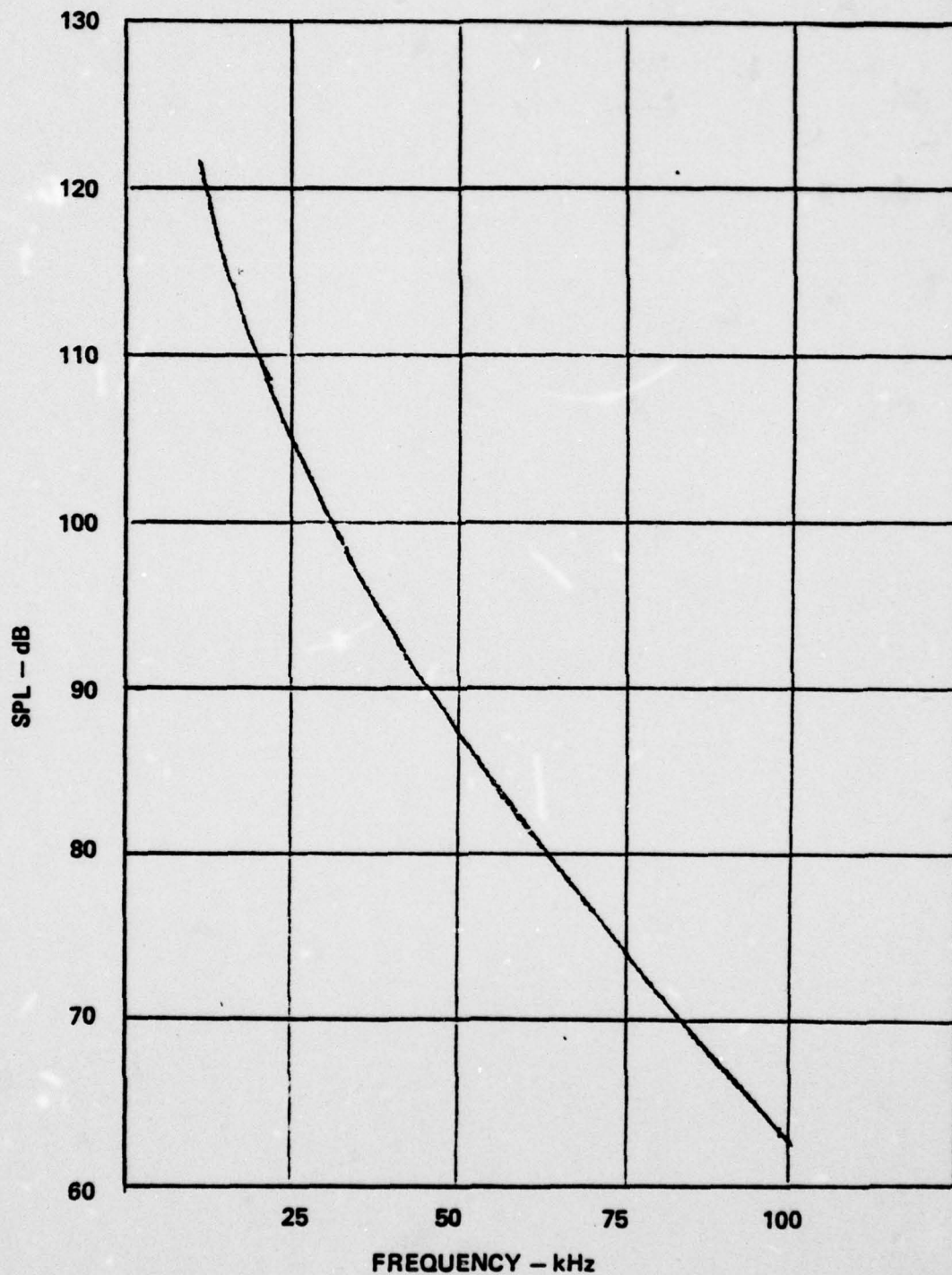


Figure 3-14. Measured Sound Pressure Levels -VS- Frequency for a Tank Traveling 38 Miles/Hour on a Concrete Road (Rubber Treads)

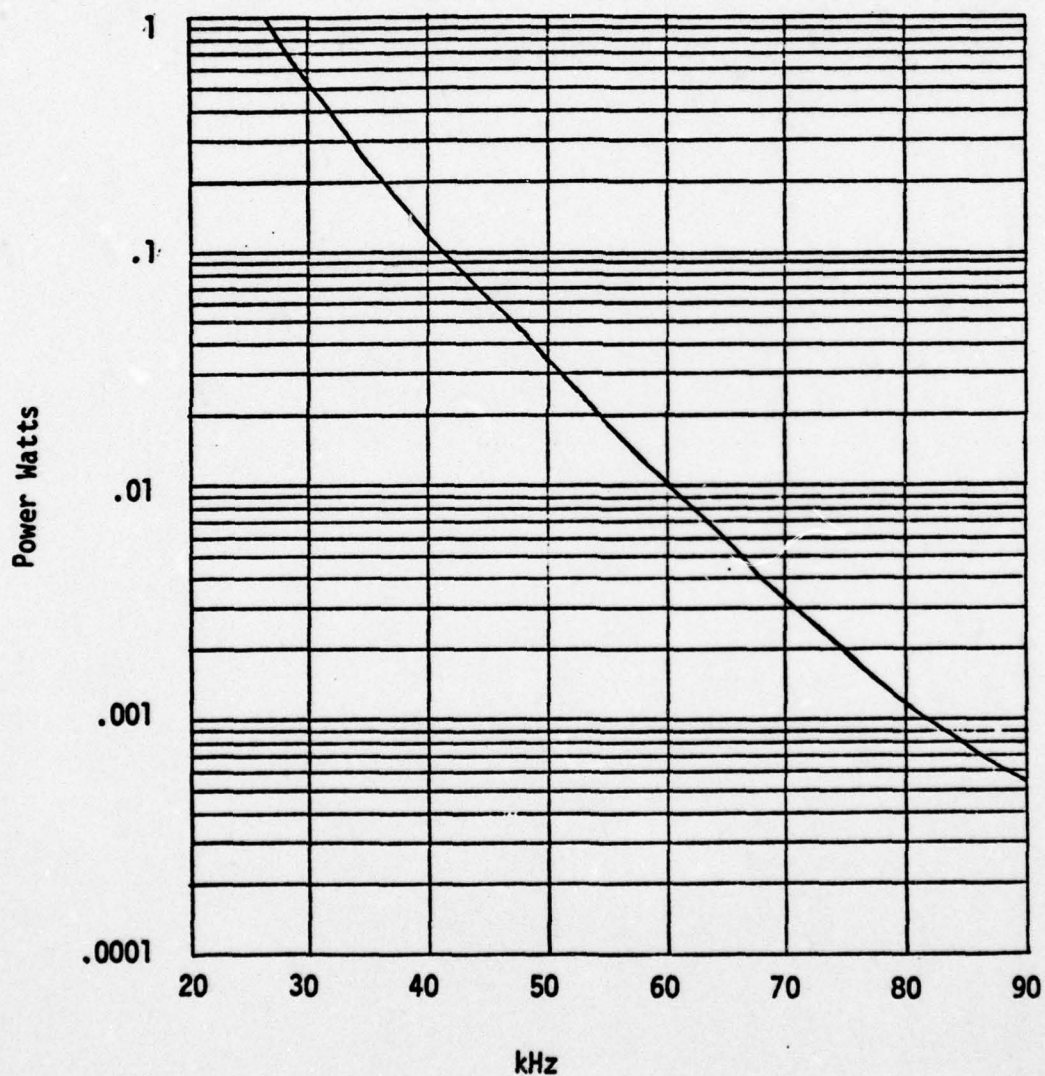


Figure 3-15: Acoustic Power for Transmission Inside an Armored Vehicle for a S/N Ratio at the Receiver of 10 dB in a Noise Environment Equivalent to Figure 3-14.

their cordless telephone showed that the distortion was not enough to impair communication. Measurements on the multipath were taken by GTE and the results are shown in Figure 3-16. Other studies are needed to determine whether the distortion is acceptable.

A typical air attenuation curve is shown in Figure 3-17. It should be pointed out that between 20 kHz and 100 kHz the curve is widely variable depending upon the amount of moisture in the air. The peak attenuation tends to occur at about 20 percent humidity. The curve shown is very close to the peak attenuation. With very dry air, the attenuation is considerably less as shown by the dashed curve.

The propagation outside of the vehicle has the problem that the air attenuation is extreme at the higher frequencies. The attenuation includes not only the geometric attenuation which is a 6 dB fall-off for every doubling of distance, but also the air attenuation as shown in Figure 3-17. Figure 3-18 shows attenuation for various frequencies as well as the geometrical attenuation only curve. The required acoustic power versus distance assuming a 40 dB background noise environment is shown in Figure 3-19. From this figure, it can be seen that it is virtually impossible to transmit 50 meters with any frequency greater than 20 kHz. If distances on the order of 50 meters are desired, the frequency used for transmission used inside the vehicle cannot be used outside the vehicle. The frequency of 60 kHz gives very little transmission distance outside the vehicle. One item is not known at this time and that is the background noise environment that exists at the ultrasonic frequencies. It is possible that the 40 dB figure is too high. Assuming that it is, the ultimate sensitivity of the receiver becomes a problem. This sensitivity can be calculated based upon the input resistance of the preamplifier connected to the transducer. A figure of about 24 dB of noise is possible under these conditions. This means the curve shown in Figure 3-19 can be lowered by a factor of 40:1. The 20 kHz curve shows that it takes 2 watts of power to transmit 50 meters. Since the maximum power that was desired is on the order of 1/10 of a watt, 50 meters would not be achievable; however, if the background environmental noise is not a factor and instead the basic resistor

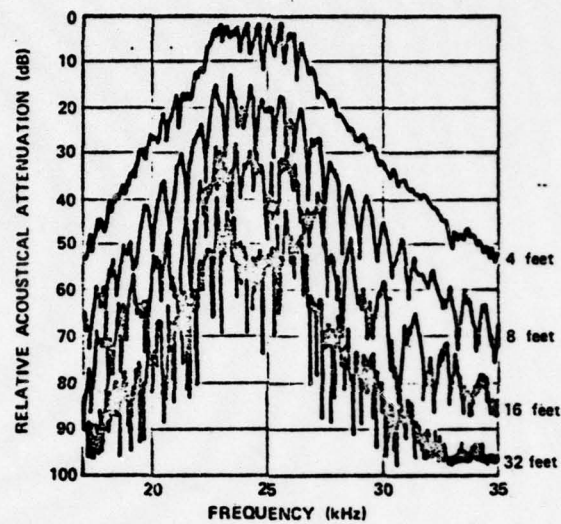


Figure 3-16. Frequency Selective Fading of an Ultrasonic Transmission

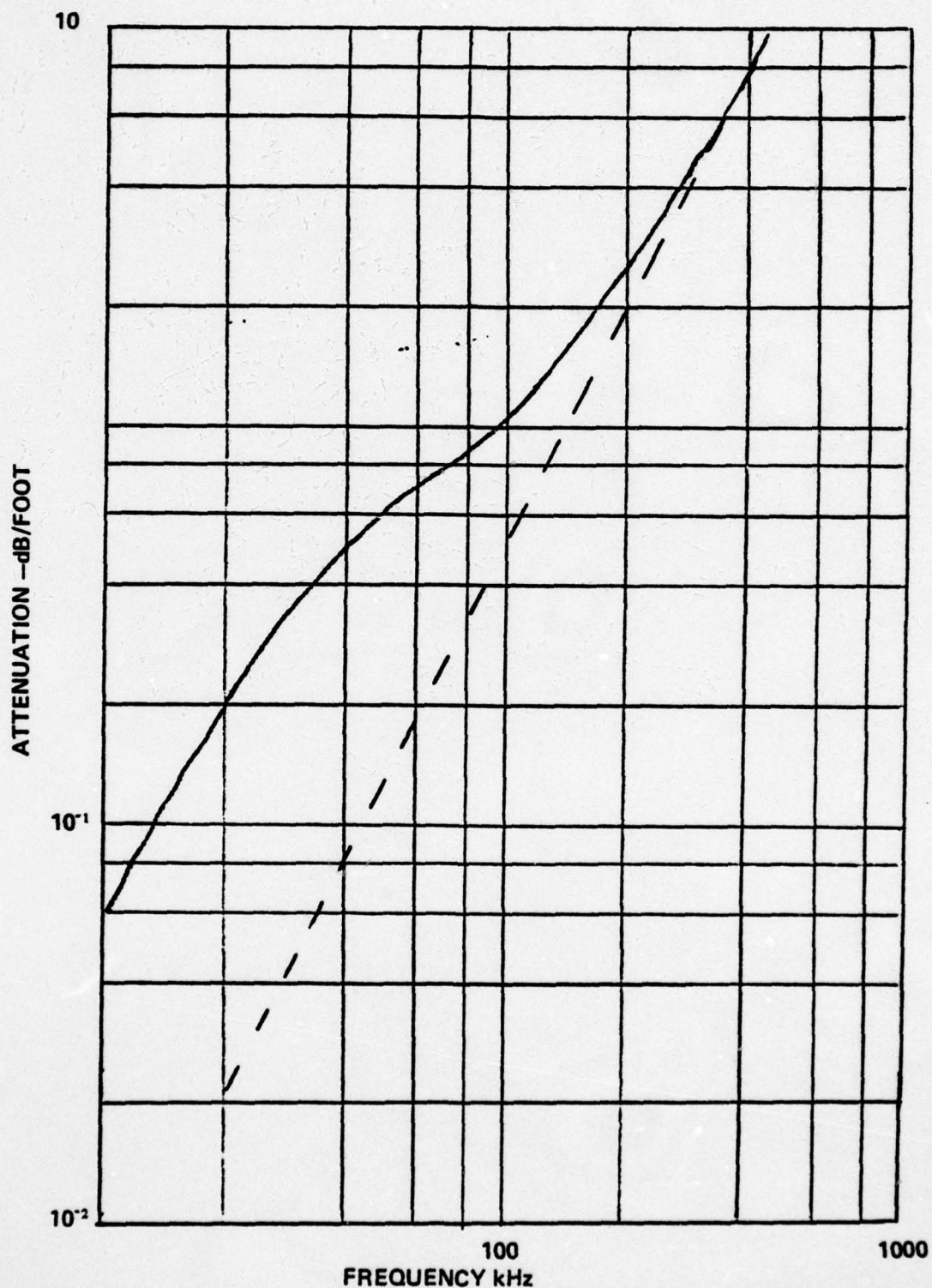


Figure 3-17. Sound Attenuation in Air (Pressure = 76 MM Hg, Temperature = 26.5°, Relative Humidity = 37%). From Sivian, J. Journal Acoust. Soc. Am. Vol. 19, p. 914 (1947).

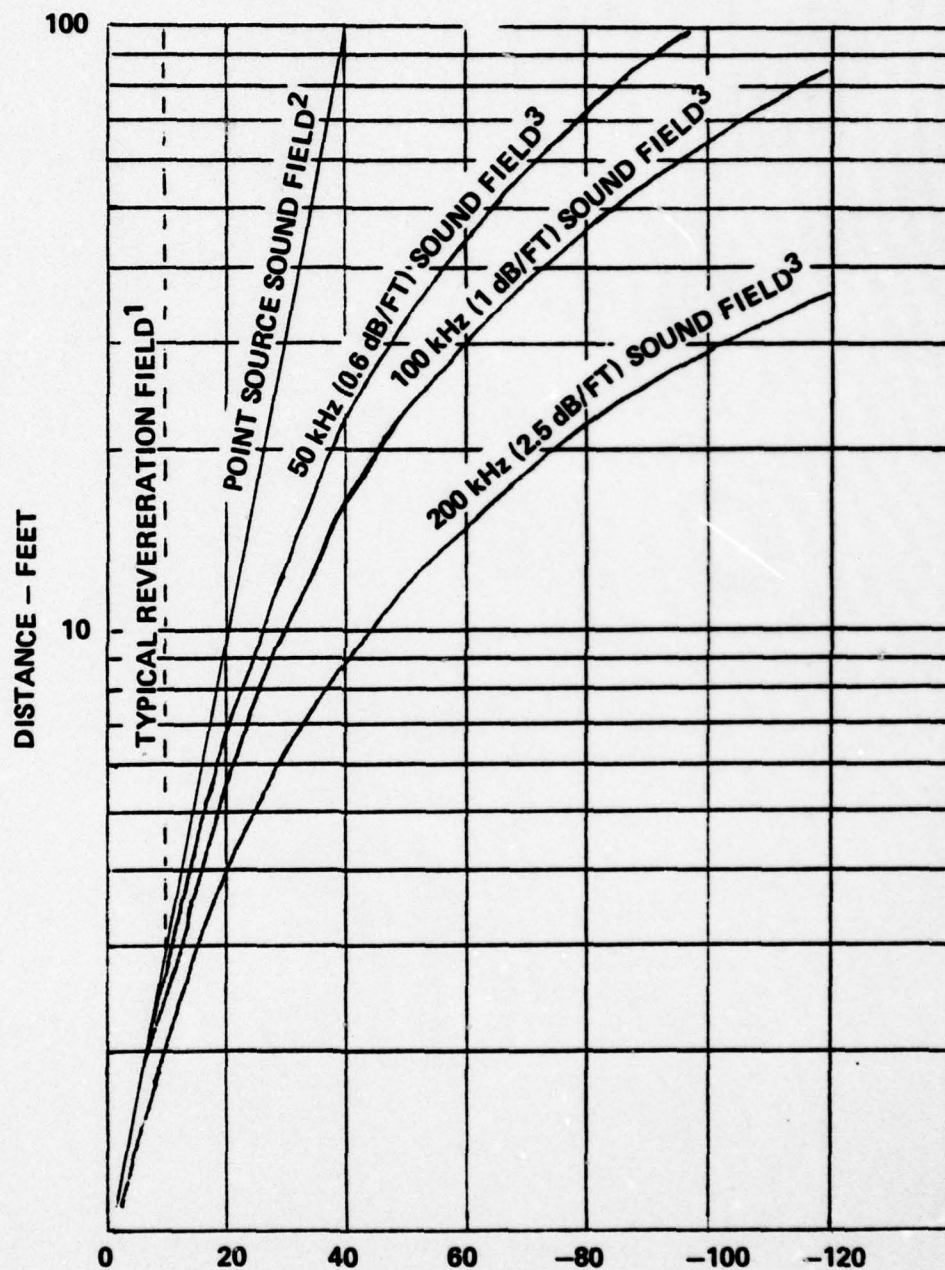


Figure 3-18.

Far Field -VS- Distance for 1) A Reverberant Room; 2) Free Field-Point Source Zero Attenuation Due to the Propagation Medium and 3) 50, 100, and 200 kHz Free Field

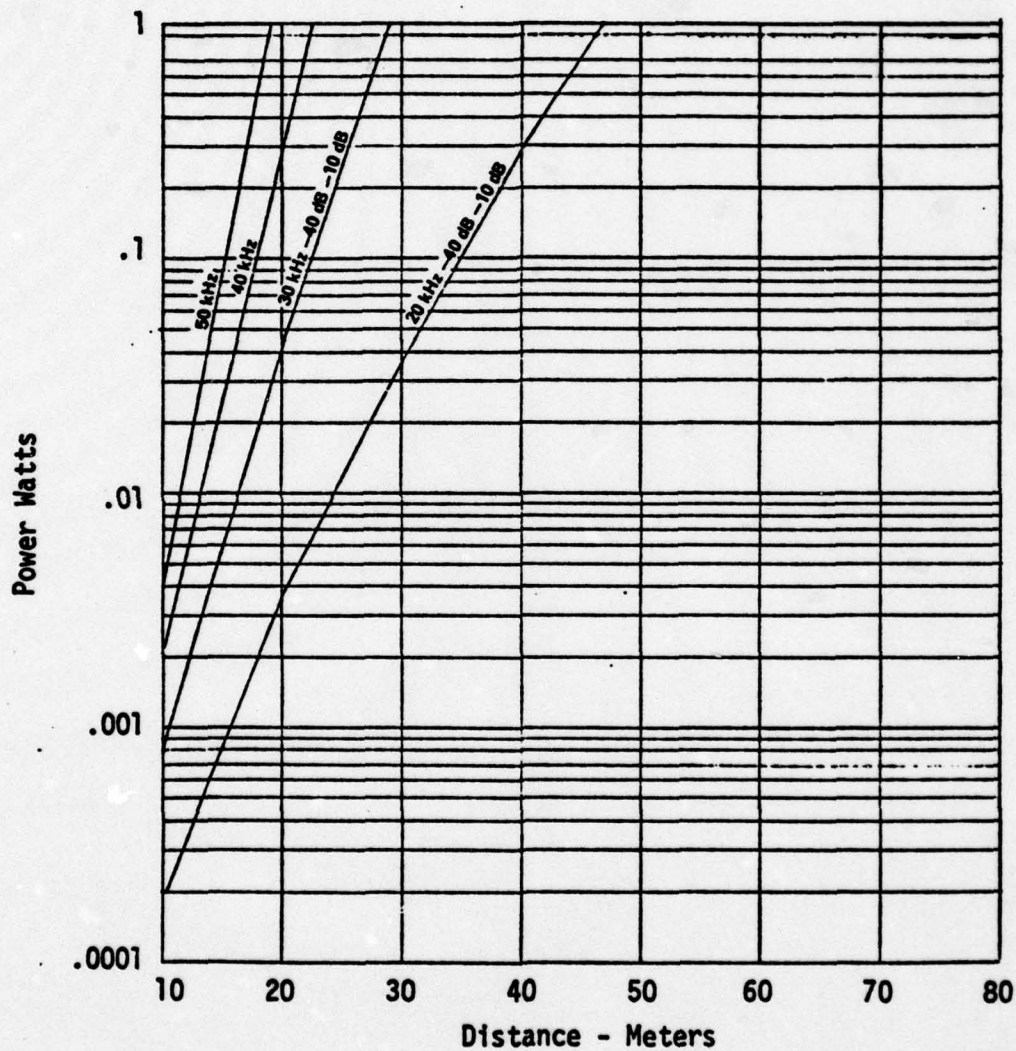


Figure 3-19: Acoustic Power Versus Distance for Several Frequencies Assuming 40 dB Environmental Noise With a Received S/N of 10 dB.

noise is the limitation, then instead of 2 watts, it would only take 0.05 watt and 20 kHz becomes a reasonable frequency to transmit 50 meters.

One of the problems at this low carrier frequency is achieving the necessary bandwidth. The transducers used tend to be high Q and is doubtful that 6 kHz can be achieved at 20 kHz. GTE achieved 3.7 kHz using TV control unit transducers. However, it is questionable that the 6 kHz bandwidth has to be maintained for transmission outside the tank. The individual would not be outside the tank under conditions of high audio noise environment; so that the added bandwidth for intelligibility is probably not necessary.

The other factor is whether the enemy can pick up the acoustic transmissions. One of the advantages of ultrasonic transmission outside the vehicle is that of the attenuation due to the air on a per unit distance basis. For example, at 20 kHz the attenuation per foot is 0.2 dB (dry air = 0.020 dB/ft). This means that at 300 meters, the signal would be further attenuated 164 dB (16.4 dB in dry air) due to the air plus another 15.6 dB due to the geometrical attenuation for a total of 179.6 dB (32 dB). Assuming that the enemy has the same sensitivity receiver, he must have approximately 9×10^{17} (1600) times the area of transducer that is located on our receiver (a parabolic reflector). This is possible in dry air only, but doubtful. If one is willing to accept somewhat shorter distances, the air attenuation can make the transmissions extremely secure. For example, at 30 kHz it is possible to transmit probably slightly in excess of 35 meters, assuming that the background noise is less than 20 dB. Attenuation per foot at 30 kHz is 0.35 dB (0.045 dB in dry air) as compared to 0.2 dB for 20 kHz. Further, the transmission is less so that at 300 meters, there would be approximately 50 dB of excess attenuation in dry air or a ratio of areas of $10^5:1$. It appears that the transmission outside the vehicle will have to be at a frequency somewhere between 20 and 30 kHz if anywhere close to the 50 meters is achieved.

It is envisioned that the system would consist of two separate systems; one for inside the armored vehicle and one for outside. Inside, the transducers would be mounted on the helmet. With a

60° beamwidth, it would take six transducers arranged around the periphery of the helmet to give the proper coverage. These transducers would take approximately 1 watt of electrical power in the transmission mode. The same transducers could be used for the receiving function if the switching can be achieved. A carrier frequency of 60 kHz would be used. The bandwidth would be achieved by the combined receiver/transmitter characteristics. The signal would be double sideband carrier suppressed modulation with the lower sideband eliminated by the attenuation characteristics of the transmitter and receiver. The transmitting and receiving elements of the station located on the vehicle periphery would have to be arranged equally around the periphery of the armored vehicle. Six would be sufficient to achieve the coverage necessary. For operation outside the vehicle, the transducer used would be of the flextural mode type and it is doubtful whether these transducers could withstand normal battle conditions. Therefore, they would have to be on a unit that would be located outside the vehicle when it is desired to transmit outside. In order to achieve a reasonable distance of transmission from the vehicle, a carrier frequency on the order of 20-30 kHz would have to be used with a bandwidth probably under 6 kHz but at least in excess of 3 kHz. The same method of transmission and modulation would be used as is used inside except with a different carrier frequency. This would require separate transducers and it means the individuals going outside the tank would have to change transducers for this purpose. The only way around this problem is to use directional type transmission which would require the individual to point toward the tank. It is assumed sufficient power could be generated within the tank to provide sufficient transmitting power in a 360° azimuth. Depending upon the degree of security of transmission desired would tend to determine whether the frequency is closer to 20 kHz or closer to 30 kHz. Overall, the ultrasonic method provides the greatest security to interception by the enemy.

WIRELESS SUMMARY:

All of the wireless systems analyzed have inherent problems which must be overcome. It is ITT-A/OD's task to select the system which will have the best probability of success. In evaluation of the

UHF and ultrasonic techniques, all the advantages and disadvantages of the system are explained. The key areas in which the system must be evaluated are:

1. Can the system meet the range requirements for external operation?
2. Are the power requirements low enough for battery operation?
3. How difficult is it for the enemy to detect or intercept wireless information?
4. What special problems must be considered to implement the system?
5. What special precautions must be taken to operate the system?

It is obvious at this point in the study that no system will satisfy all of the above requirements of the above key areas.

The following tabulation of the two wireless systems which follow will be used to select the most viable system.

ULTRASONIC:

1. Attenuation in air increases as the cube of the distance and 50 meters would not be practical. A useful range of 30 meters would be the approximate usable distance.
2. Transducer efficiency of 10 percent for converting electrical energy to acoustic energy.
3. Because of the attenuation characteristics of acoustic waves, detection would be very difficult.
4. There is a high level of noise at the low acoustic frequencies inside the tracked vehicle when it is in motion. The frequency of the internal wireless system must be 50 to 70 kHz to operate above these high energy level frequencies.

The attenuation increases as frequency increases and therefore a frequency of 20 kHz to 25 kHz must be used for outside the vehicle. The requirement then is for

two different types of transducers. The radiation pattern is not sufficient to operate an omni directional system. Four transducers will be needed.

Standing waves which occur when operating inside the tracked vehicle cause distortion. This distortion can be in the area of 10 to 15 percent.

Making a transducer which will meet all of the MIL specifications is very difficult especially for the abuse to the transducer mounted on the exterior of the tracked vehicle. Transducers must have the capability to "breathe" (allow air to the back side of the transducer element) which makes them vulnerable to dust, dirt, and water.

5. Bandwidth is very difficult to achieve with the acoustic transducers and therefore the audio bandwidth may suffer. Single sideband operation would be required for this application.

UHF (415 MHz)

1. The UHF system can easily radiate the maximum required distance.
2. Using all Class A biasing, the final output transistor will operate at 25 percent efficiency.
3. Using UHF implementation of the system must be done carefully and power levels kept as low as possible to prevent interception.
4. Other radio equipment on board tracked vehicles will interfere with the intercom if the levels are set too low.
5. To reduce the intercept hazard it is desirable to install low pass filters in the antenna lines.

Table 3-V. UHF -Vs- Ultrasonic

	Ultrasonic	UHF
Range Requirements	Not capable of maximum range requirements	Yes
Battery Operation	Fair	Good
Intercept	Difficult	Fair
Implementation Problems	Requires multi-transducers Very difficult to protect from environment	Fair
Special Precautions	Special send and Receive Transducer for B.W.	Lowpass filter in antenna lines or other considerations to prevent interception

Comparing the UHF and ultrasonic systems (Table 3-V), the ultrasonic has one quality that is very desirable. It would be very difficult to detect. There are, however, other considerations which make the ultrasonic unfeasible. One, the number of transducers required to operate wireless both inside and outside a tracked vehicle and two, the difficulty of making the transducers impervious to the environment.

The VHF system requires special compensation or reduced system capability to compensate for intercept threat. It does however have all the capabilities required to implement a wireless intercom system. It is felt by ITT-A/OD that the UHF wireless system has the highest probability of success.

The UHF wireless analysis is summarized in Table 3-VI. It is clear that the UHF wideband system gives 15 dB added range protection from interception. It is however not compliant with the frequency band at which it is to operate. The low RF power requirement of the UHF system may allow for special considerations.

There is a requirement for real world data of low power UHF systems which can be achieved by either wideband or narrowband test signals.

4.0 INTERCOM SIGNAL DISTRIBUTION

In the previous quarterly report a simplified Time Division Multiplexed (TDM) signal distribution system was developed which had the following operating characteristics:

1. STAR Distribution - Individual cables route voice and control signals to and from the Command Station and User Stations.
2. Low TDM Data Rate - TDM signals are transferred at 240 KBPS.
3. Reduced Wiring - Only two lines are required for two-way TDM communication.
4. Improved EMI Noise Immunity - Digital communication techniques provide for rejection of additive noise.

During the present reporting period detailed circuit designs for implementation of this TDM system were developed. Parts were ordered such that a TDM breadboard could be built for test and evaluation. Also, a cost analysis was performed to determine the cost-effectiveness of a TDM signal distribution approach versus more conventional Space Division multiplexed signal distribution techniques. Key factors which this cost analysis investigated are:

1. Electronic Circuit Cost - Does the large number of I.C. circuits required in a TDM system significantly impact system cost?
2. Electronic Circuit Reliability - Does the large number of I.C. circuits required in a TDM system significantly impact system reliability? Are MIL-STD-38510, Class B components required to meet system reliability and if so, what is the cost impact of these circuits?
3. Cable Cost - Is there a significant savings in cable and connector costs when implementing a low wire count TDM system versus a high wire count SDM system?

Tentative results of this cost and reliability analysis showed that if Class C MIL-STD-38510 parts can be used in the TDM system then the additional cost of TDM circuits is offset by the reduced cost for cables and connectors. Preliminary reliability analysis in accordance with MIL-HDBK-217B, however, shows that the system MTBF for Class C parts versus Class B parts is 3000 hours versus 17,000 hours. It is pointed out that the formulas specified in MIL-HDBK-217B for calculating CMOS component failure rates do not take into account operating supply voltage. A comparison of failure rates for Motorola Class C CMOS components and Class B components (per MIL-HDBK-217B) are given as follows:

Reliability Data Source	Device Type	Operating Voltage	Failure Rate		
			55°C	85°C	125°C
Motorola	Composite Avg. of 32 Devices	10V DC	.025%/10 ⁶ Hr	.92%/10 ⁶ Hr	28%/10 ⁵ Hr
		18V DC	.6%/10 ⁶ Hr	15%/10 ⁶ Hr	.43%/10 ³ Hr
MIL-STD-38510 Class B per MIL-HDBK-217B	4013 Dual-D Flip-Flop	Not Specified	1.34%/20 ⁵ Hr	Not Calculated	Not Calculated

From the above data it is seen that a Motorola CMOS part, which is manufactured according to MIL-STD-883 Class C specifications, exhibits significantly lower failure rates if operated at lower than maximum D.C. supply voltage. The failure rates exhibited by Motorola devices are significantly lower than other manufacturers.

If the data for Motorola components is substituted for values calculated using MIL-HDBK-217B, then the system MTBF of 12,000 hours can easily be met.

To avoid the use of high cost Class B parts it is recommended the following steps be taken in design of the intercom system:

1. Operate CMOS parts at 10V DC
2. Select a vendor such as Motorola, who is known for producing quality parts.

Typical cost ratios incurred by using Class B versus Class C parts are 10 to 1. In terms of system life-cycle cost the use of Class C parts becomes almost mandatory.

The following subsections present a detailed description of the TDM system design and analyses the relative cost of this TDM system versus a more conventional SDM system.

Prior to describing each TDM and SDM system a baseline signal distribution system is presented such that general operating parameters can be specified.

Baseline Signal Distribution System

A baseline architecture has been developed for the intercom voice distribution. This baseline design sets forth the design requirements which must be met when implementing a particular signal distribution technique. A block diagram of this baseline system is shown in Figure 4-1. Key features of this baseline system are as follows:

1. STAR Signal Distribution - Individual crew station I/O networks provide for distribution of voice and control signals to and from each crew station.
2. Distributed Signal Amplification and Power Supplies - Individual MIC amps, phone amps and power supplies are provided at each crew station. This reduces size of power supply and amplifier networks at commander station. This approach also simplifies the design of TEMPEST isolation networks in the power distribution system.

3. Radio Access and Control - Control bits are routed from each crew station to its respective crew station I/O. The control bits select one of five intercom signals (INT only, All, R/T #1 plus INT, R/T #2 plus INT, R/T #3 plus INT) to be routed to the crew station for reception by the crew member. These control bits, which include radio PTT, are also routed via the Station I/O control bus to the intercom controller. Each crew station's control bits are processed and routed to the R/T transmit Select Module, where crew station voice signals are connected to the appropriate radio. A conference bridge provides for summing all crew member voice signals onto the intercom party line.
4. Ancillary Intercom Voice Distribution Function - a) Commander Station Audio I/O, b) Auxiliary Command Station Interface, c) Audio Accessory I/O, d) Tel/Remote I/O, e) Data Modem I/O and Switch.

To provide the above operating features, the baseline system in Figure 4-1 is composed of several hardware module which include:

1. Radio XMIT Select Module
2. Radio RCV Module
3. Crew Station I/O Modules (7)
4. Commander Station Audio I/O
5. Auxiliary Command Station Interface
6. Crew Stations - includes MIC Amp, phone amp, power supply and radio select controls
7. Audio Accessory and Tel/Remote I/O
8. Data Modem I/O Switch

Depending on the type of voice distribution system implemented, the electrical design of these hardware modules will vary to a lesser or greater degree. However, there are certain electrical hardware components which will be required regardless of what type of voice distribution system is employed. These items include:

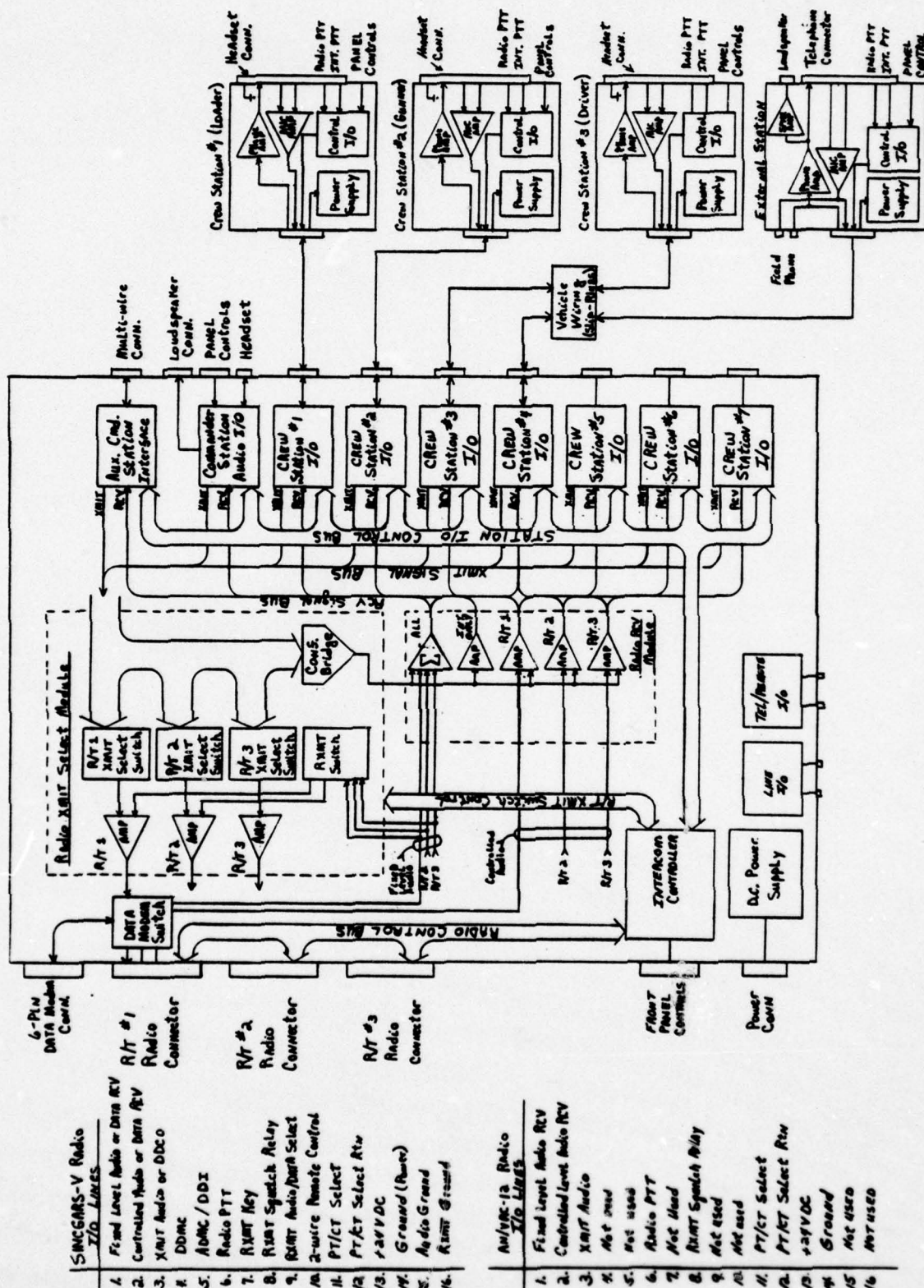


Figure 4-1: Baseband Signal Interconnection Block Diagram

1. Radio XMIT Select Switches
2. Conference Bridge
3. Command Station Power Supply
4. Crew Station Power Supply
5. Crew Station MIC Amp
6. Crew Station Phone Amp
7. Commander Station Audio I/O with Loudspeaker Amp
8. Panel Controls
9. Radio RCV Signal Routing Amps
10. Intercom Controller
11. Control Bus Interface at Station I/O

The following subsections present a detailed design of a TDM and SDM voice distribution system and identifies those electrical hardware items which are required in addition to the above base system components. The added cost of additional hardware required to meet each system configuration is compared in the following subsections.

TDM Signal Distribution System

In the previous quarterly report a simplified block diagram and timing diagram of the proposed TDM voice distribution system was presented. A more detailed block diagram of how the TDM network interfaces within the intercom system is shown in Figure 4-2. In this diagram it is seen that the implementation of the TDM system will impact the following intercom modules:

1. Radio XMIT Select Module - Seven CVSD decoders are required to convert digital CVSD voice to an analog format.
2. Radio RCV Module - Five CVSD encoders are required to convert analog voice to a digital CVSD format.
3. Crew Station I/O - An all digital TDM network provides for multiplexing and demultiplexing of digital voice and control bits onto a single 2-wire TDM line.
4. Crew Station - An all digital TDM network is required at each crew station to provide for the multiplexing and de-multiplexing of digital voice and control infor-

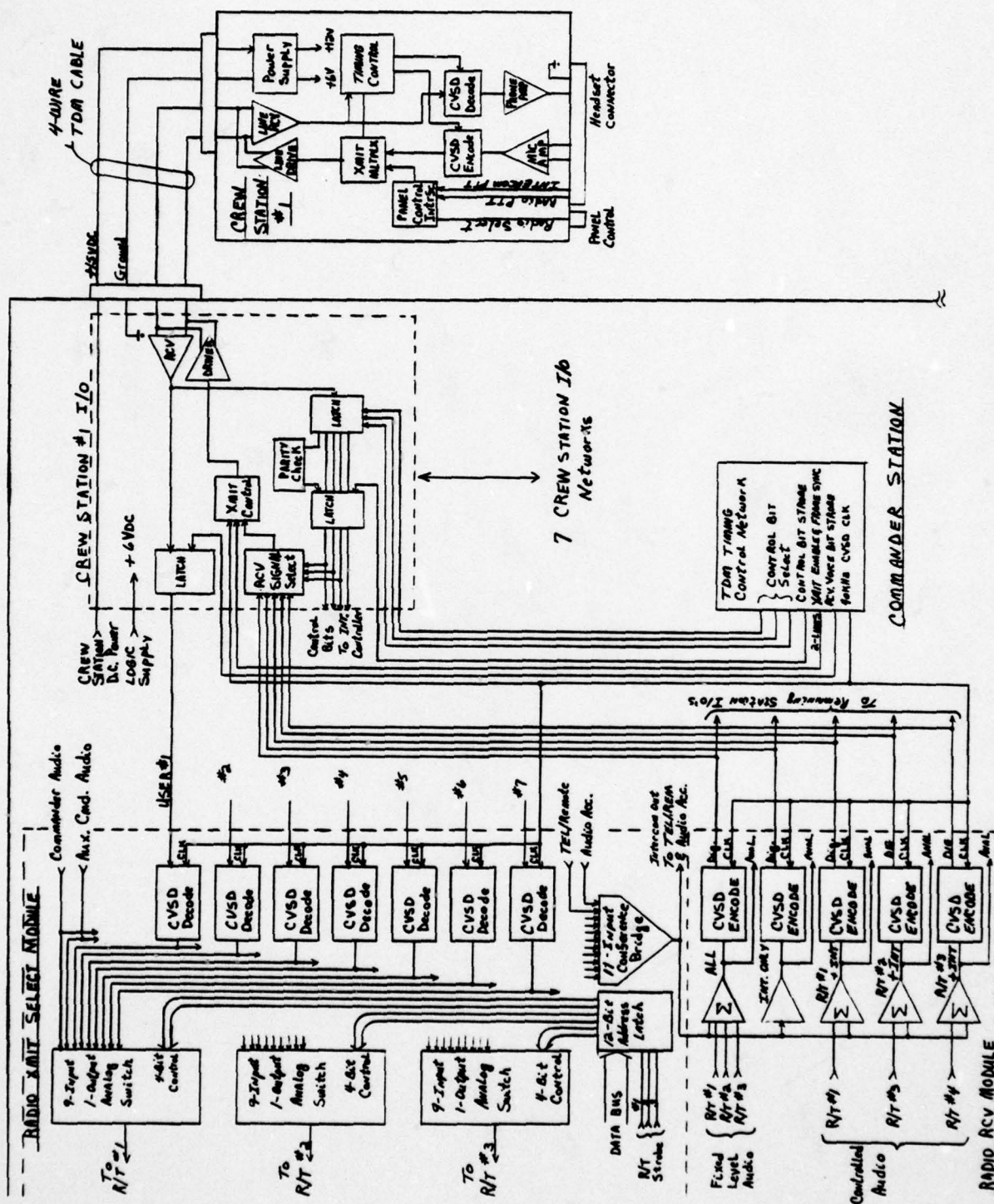


Figure 4-2: TDM Components of Intercom System

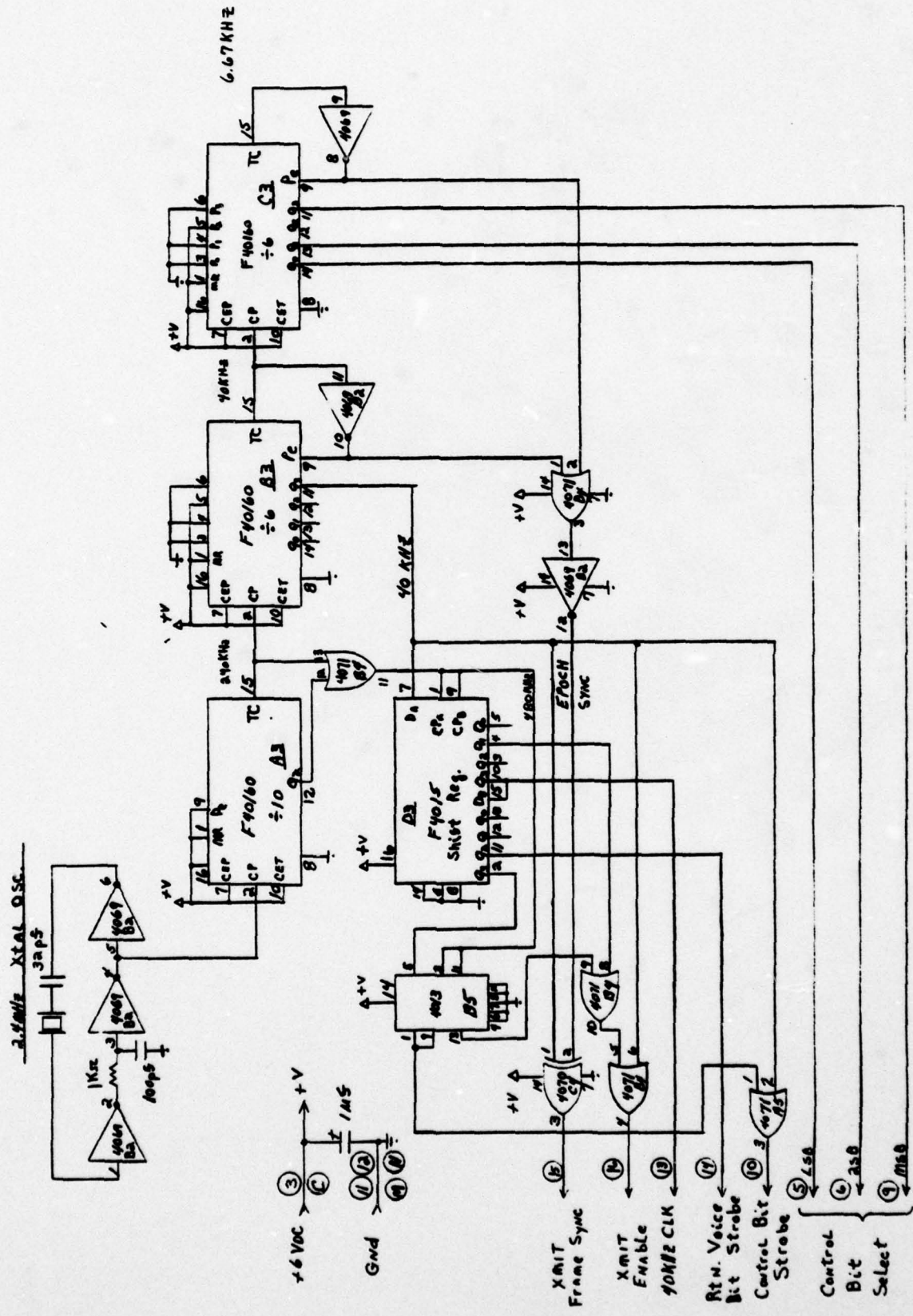


Figure 4-3: Command Station TDM Timing Control Network

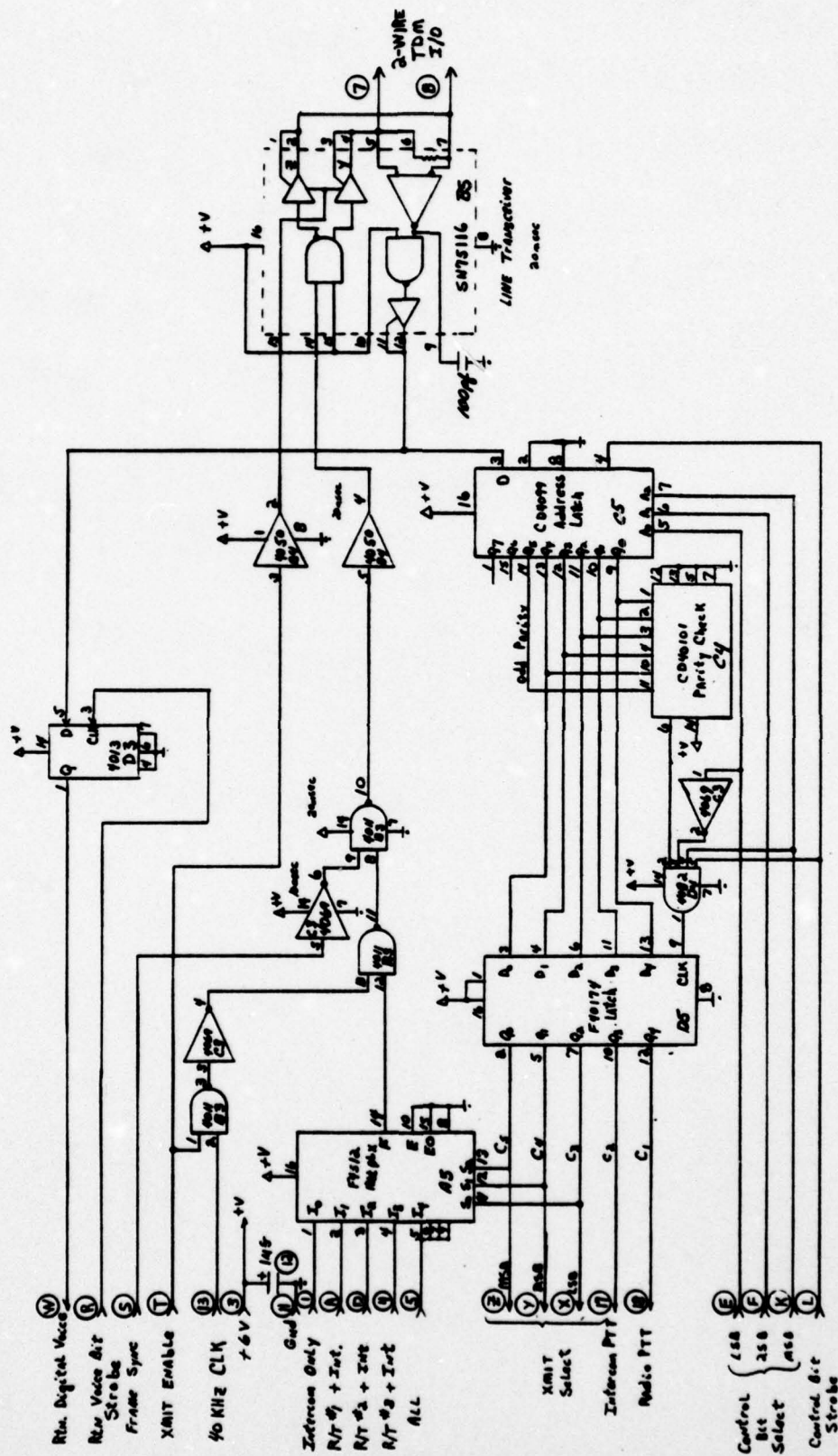


Figure 4-4: Crew Station I/O at Commander Station

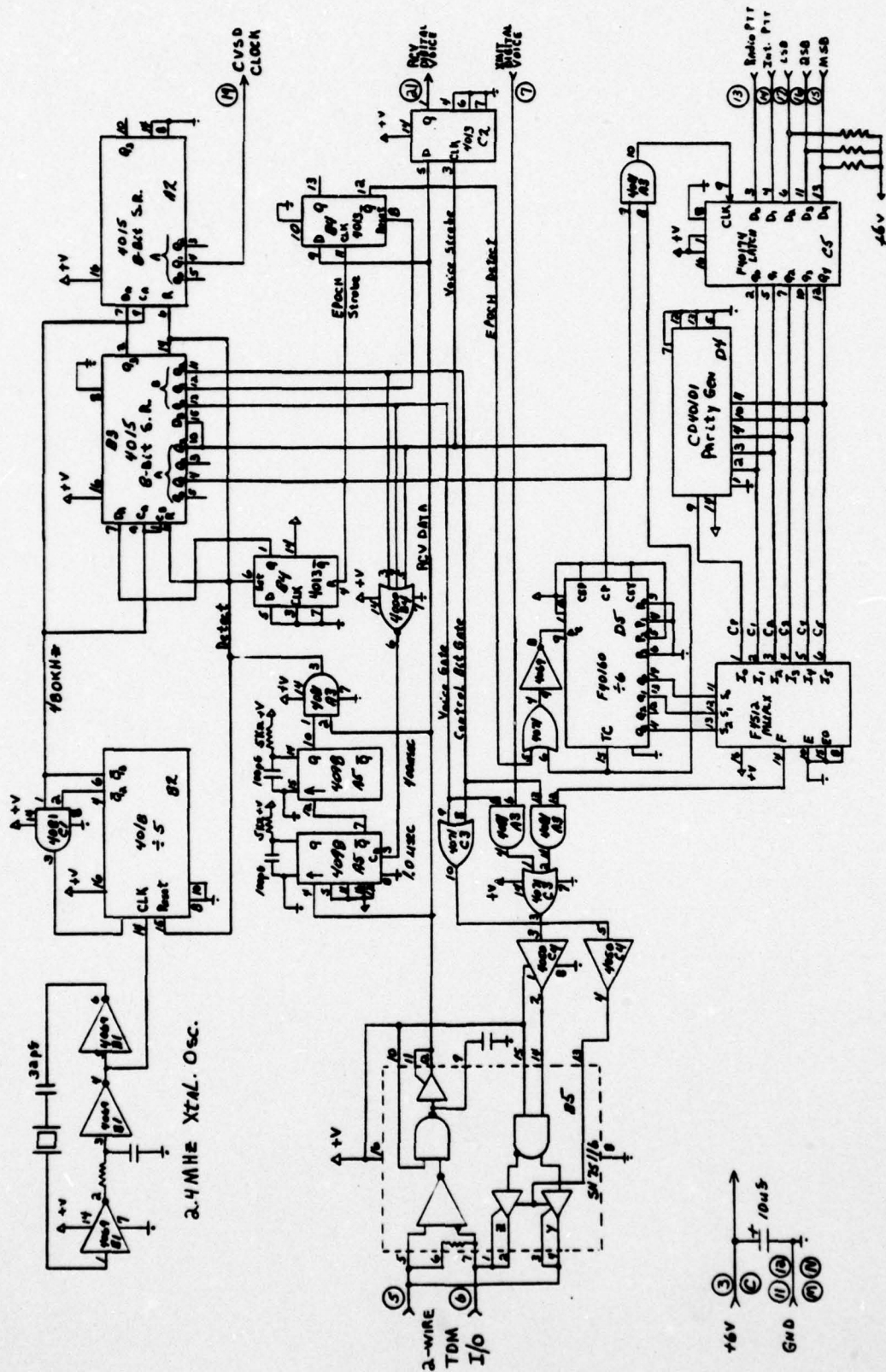


Figure 4-5: Crew Station TDM Network

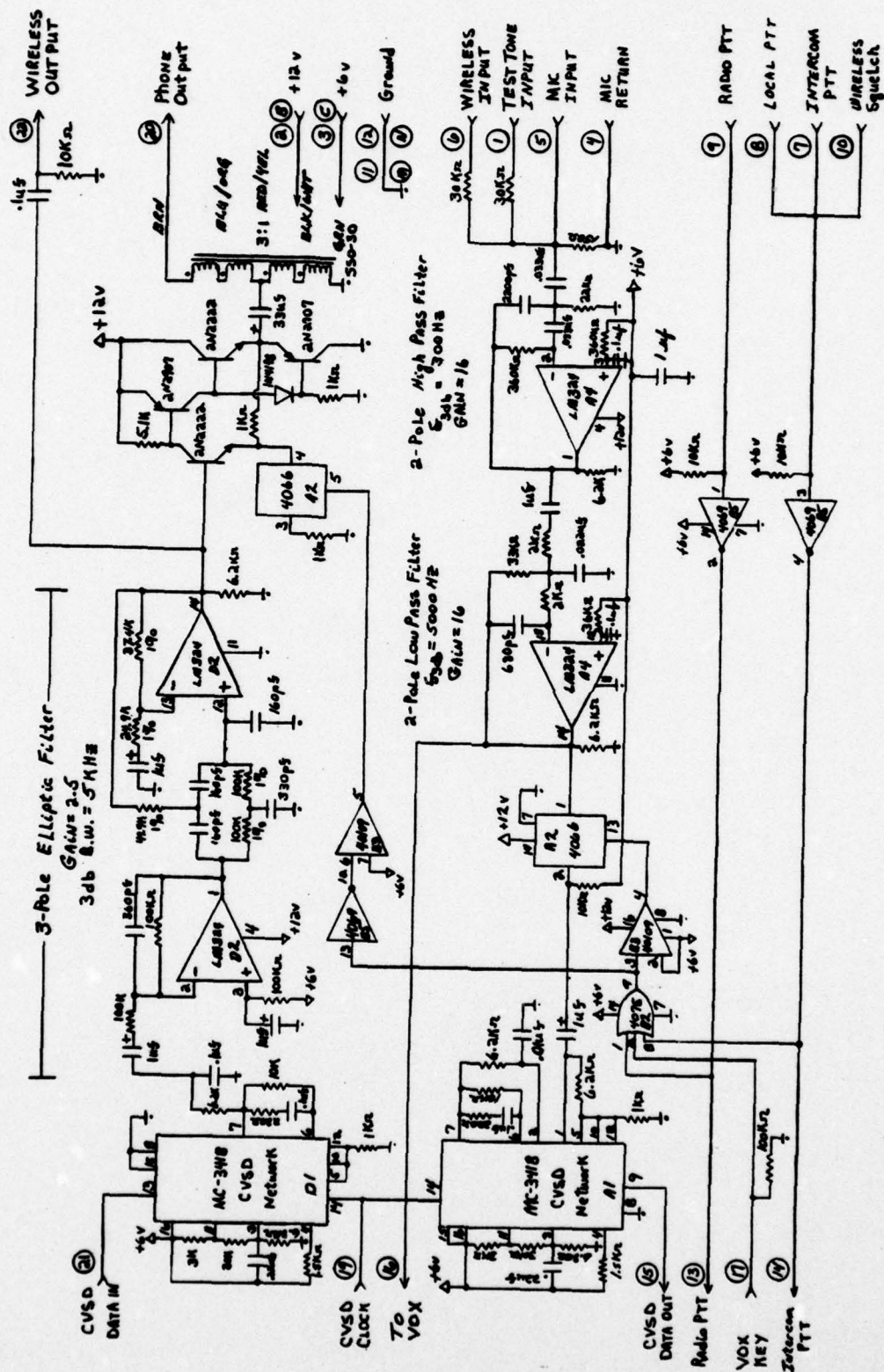


Figure 4-6: Crew Station Audio I/O Network

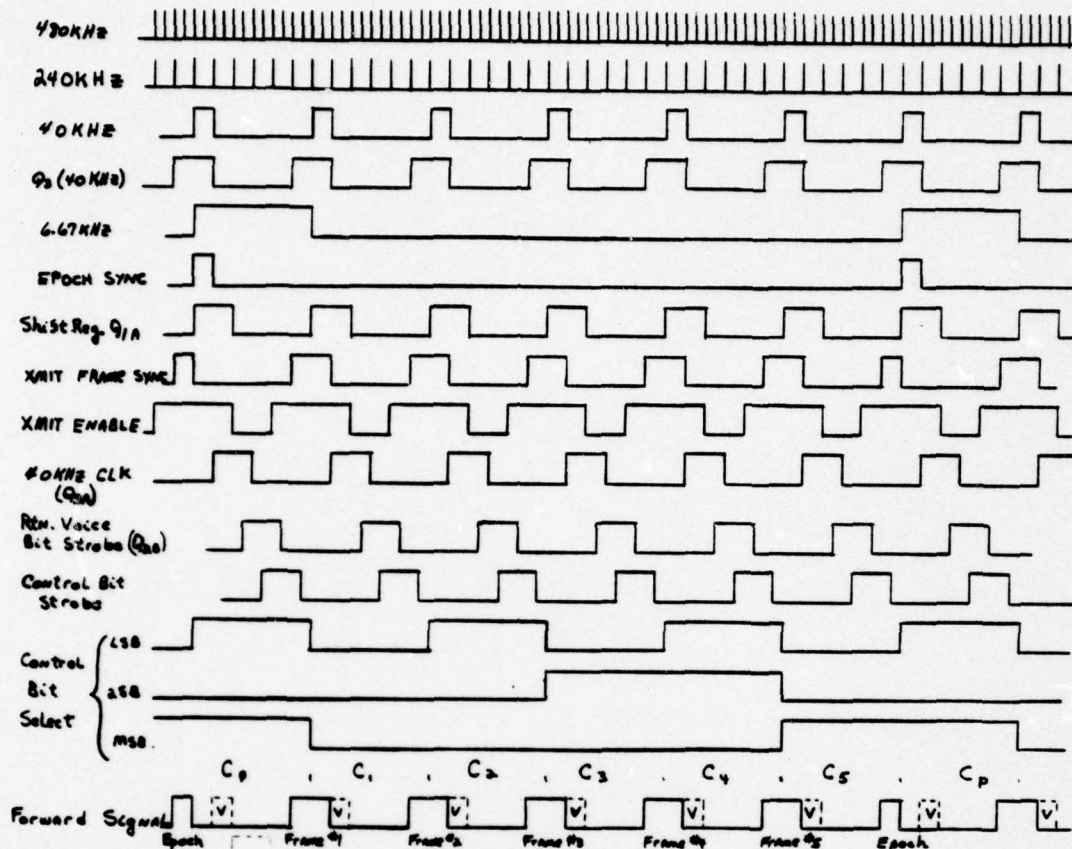


Figure 4-7A: Command Station TDM Timing Diagram

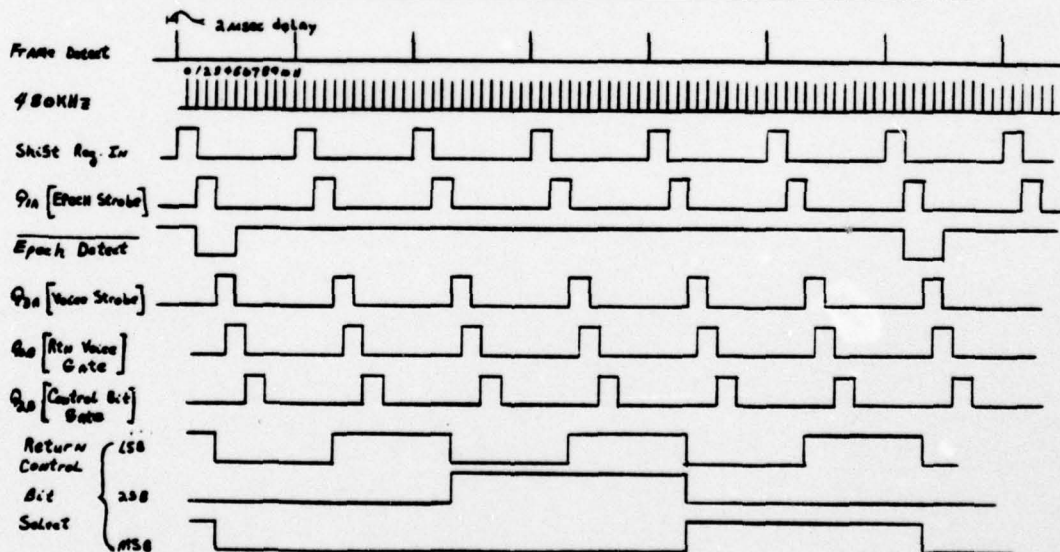


Figure 4-7B: Crew Station TDM Timing Diagram

mation. In addition, two CVSD coder/decoder networks are required to convert analog voice to digital voice and vice versa.

5. Commander Station - An additional module (TDM Timing Control) is required at the Command Station to operate the TDM system.

To evaluate the performance of the proposed TDM system, detailed circuit designs for each of the above TDM circuits were developed. Schematic diagrams of the TDM Timing Control Network, Crew Station I/O, Crew Station TDM network and Crew Station Audio I/O network are shown in Figures 4-2 through 4-6, respectively. A detailed timing diagram for the TDM system is shown in Figures 4-7a and 4-7b to illustrate the detailed operation of the TDM voice distribution system. All parts required for fabrication of a single TDM wireline link have been placed on order. The circuits in Figures 4-3 through 4-6 are used in the following subsections to generate parts lists for determining the approximate cost for a TDM system bill of material.

At the time of this report the only portions of the TDM system which have been fabricated and tested are the CVSD encoder/decoder network, microphone amplifier and headphone amplifier circuits. The performance of these networks are discussed in the following subsection.

CVSD Circuit Evaluation

Currently two semiconductor companies manufacture CVSD integrated circuits which are suitable for operation in the current TDM voice distribution system. These companies and respective CVSD devices are Motorola (MC-3418) and Harris (55532). The salient operating features of each circuit is summarized in Table 4-I. From the data in this table it is seen that the Harris HC-55532 is designed specifically for operation at 32 kbps and while operation at higher bit rates is possible, the respective performance will not be optimum. The advantage of the HC-55532 is that no external components are required for its operation. The Motorola MC-3418, through the addition of external

Table 4-I. CVSD Network Operating Characteristics

Design Feature	Motorola MC-3418	Harris HC-55532
1. Fabrication Technique	I ² L with CMOS Compatible Outputs	CMOS
2. Supply Voltage	4.75 Vdc to 15 Vdc	5.0V to 7.0V
3. Min Step Size	Externally Adjustable Nom = 4 mV	Fixed Internally = 4 mV
4. Step Size Ratio	Externally Adjustable Nom = 28 dB	Fixed Internally = 26 dB
5. Syllabic Time Constant	Externally Adjustable Nom = 6 msec	Inversely Proportional to Clock Rate = 4 msec @ 32 kBPS
6. Low Pass Time Constant	Externally Adjustable Nom = 1 msec	Inversely Proportional to Clock Rate = 1 msec @ 32 kBPS
7. Quieting Control	Not Available	External APT Control Forces I-O Pattern during Unkeyed Conditions
8. Step Size Algorithm	Externally Selectable a. Linear b. Exponential c. Variable attack/delay time constant	Fixed Internally Linear
9. Multi-Pole Feedback	Externally Selectable a. Two-Pole Integration	Fixed Internally
10. Bit Rate	100 kBPS Maximum Design parameters adjusted externally to provide optimum performance at selected bit rate	64 kBPS Maximum Circuit internally designed for optimum performance at 32 kBPS

components, can be tailored for operation at bit rates from 10 kBPS to 100 kBPS. This flexibility of the MC-3418 provides for its superior signal-to-quantizing noise performance and excellent voice quality. The disadvantage of the MC-3418 is that several external resistors and capacitors must be added to provide this performance.

At the time of this report samples of both the MC-3418 and HC-55532 have been ordered. To date only the MC-3418 has been bread-boarded and evaluated. A schematic diagram of a portion of the MC-3418

CVSD network and output filter is shown in Figure 4-8. In this figure analog voice is digitally encoded at 40 kbps and the CVSD integrator output is a digitally constructed replica of the input voice signal. The syllabic filter and integrator time constants are determined by external resistors and capacitors. The CVSD analog voice is filtered by an active 3-pole elliptic filter. This filter provides a sharp cut-off above 5 kHz and nulls out CVSD clock subharmonics at 10 kHz.

The CVSD circuit in Figure 4-8 employs 2-pole filter network in the integrator feedback path. Two feedback filter arrangements were tested: single-pole and two-pole. In accordance with Motorola application notes, the 2-pole filter arrangement provides about a 2 dB increase in signal-to-quantizing noise performance. The present 2-pole CVSD circuit provides a SNR of +28 dB over an input dynamic range of 12 dB. In addition it was noted that the 2-pole filter configuration decreased the metallic sound of voice signals. In the area of voice quality the following characteristics of the CVSD network were noted:

1. Voice Intelligibility - At the high operating clock rate of 40 kHz and the operating bandwidth, the CVSD network will provide near perfect voice intelligibility performance with an articulation index of at least 0.9 or greater.
2. Voice Quality - At a clock rate of 40 kHz and an operating bandwidth of 5 kHz, there is a detectable metallic quality to the voice signal. An increase in clock rate to 50 kHz or a narrowing of audio bandwidth removes this metallic quality.
3. Speaker Recognition - Speaker recognition is excellent.

As a result of these tests, it is clear that CVSD LSI circuits such as the Motorola MC-3418 are available for use in a TDM intercom system. These circuits are capable of providing excellent voice reproduction at a low cost. The Harris HC-55532 remains to be evaluated. After a comparative evaluation of these two devices a final decision will be made on CVSD clock rate and audio bandwidth.

In the area of audio bandwidth, it was pointed out above that narrowing of the audio bandwidth to 4 kHz improved the voice quality of the CVSD signal by filtering out quantizing noise components which result in a metallic voice characteristic. The current intercom specification (DS-AF-0246A) calls for a system audio response of 300 Hz to 6 kHz in specification paragraph 3.9. A brief analysis of this requirement will show that a wide audio bandwidth out to 6 kHz provides little increase in voice intelligibility performance of a communication system. In 1947 French and Steinberg developed an Articulation Index (AI) for measuring the intelligibility of speech. In this method the audio spectrum was subdivided into 20 frequency bands which contribute equally to speech intelligibility. The three upper frequency bands are: Band 18 (3650 to 4250 Hz), Band 19 (4250 to 5050 Hz) and Band 20 (5050 to 6100 Hz). If filtering is employed in the intercom system such that the audio response is reduced from 6 kHz to 4 kHz, then only three of the 20 bands will be eliminated. The truncation at the high end in combination with truncation of Band 1 (200 to 330 Hz) at the low end will reduce the Articulation Index of the system to 0.8. Voice communication systems with an AI of greater than 0.7 are considered very good to excellent in quality.

If a TDM voice distribution is implemented in the intercom system with CVSD voice processing, it is recommended that a system bandwidth of 300 Hz to 4 kHz be specified. This bandwidth would provide good voice quality at 40 kHz clock rate and at the same time would not degrade the AI significantly.

SDM Signal Distribution

A viable alternative to TDM voice distribution techniques is the use of space division multiplexing, where signals are distributed on individual wirelines to the respective intercom users. This technique becomes particularly useful if the wire count can be reduced below the present 14 signal lines which are used to connect the AM-

1780 and C-2297 in the AN/VIC-1 system. During this past reporting period the details of an SDM system were developed such that only a 10-line signal cable is required to interconnect the crew station and command station. This section presents the general details of this SDM system. The section which follows compares the relative technical performance and cost of this SDM voice distribution system versus the TDM system presented in the previous section. The design of the SDM system in this section follows the requirements set forth for the baseline system presented earlier.

A block diagram of an SDM voice distribution system is shown in Figure 4-9. It is seen that the architecture of this SDM system is very similar to the TDM system in that many of the modules and module electrical circuits are similar. The salient features of the SDM system of Figure 4-9 are:

1. Single Forward Voice Line - One of five possible intercom or radio voice signals are switched onto a single line to the user. The user selects the desired voice channel via his crew station audio select control. This control is a five position binary coded switch. The binary coded switch controls are transferred via line drivers/receivers to the crew station I/O. At the crew station I/O the binary coded audio control bits control the 5-line analog switch and are also routed to the Intercom Controller, which processes the control bits prior to operation of Radio XMIT select switches.
2. Return Voice Signal - The microphone signal from each user station is routed via a balanced line to the crew station I/O. A balanced line is used to isolate power supply and forward signal ground currents from the user MIC signal. This design technique minimizes crosstalk and eliminates the leakage of RED signal ground currents onto a hot MIC line which is connected to a BLACK transmitting radio.

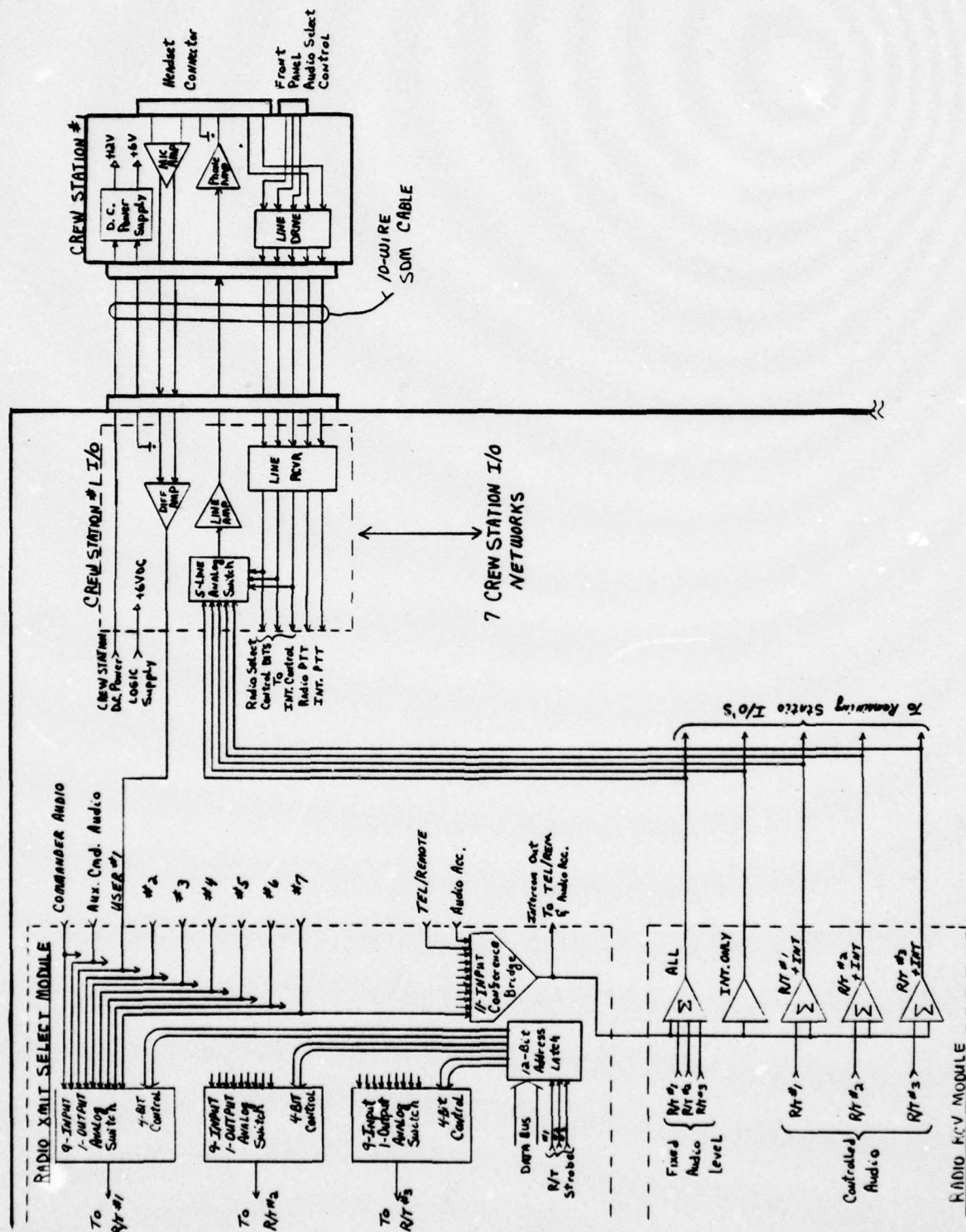


Figure 4-9: SDM Voice Distribution Block Diagram

3. Minimal Circuitry - There is a minimum amount of electrical circuits required to transmit and receive the intercom voice signals. This is in contrast to the relatively large amount of digital IC networks required in the TDM system. In general, however, the same amount of analog amplifier networks are required in both the SDM and TDM systems.
4. Multi-Wire Cable - A 10-wire cable and associated connectors are required for routing user signals in the SDM system. This is in contrast to the 4-wire TDM cables.

TDM Versus SDM Performance and Cost Trade-Off

The principal technical advantages and disadvantages of TDM versus SDM signal distribution systems were presented in the ITT-A/OD proposal (Section 2.2.1.2). That comparison is summarized in the following table:

Table 4-II. TDM Versus SDM Technical Performance

Technical Item	TDM	SDM
Electrical Noise Immunity	The absolute logic levels in a TDM system provide a high degree of immunity to additive electrical noise and crosstalk	The analog signals in a SDM system are susceptible to additive electrical noise and crosstalk. Balanced interconnect lines can be used to reduce interference, but the cost of such balanced lines adds significantly to system cost.
Voice Intelligibility	Digital voice encoding techniques such as CVSD provide a voice quality which is equal to an analog system.	Voice quality is excellent
Cable Size	Reduced cable size provides for ease of equipment installation. This is particularly true for the next generation intercom which must service up to 8 users.	Large cable size makes connector location difficult and cable routing cumbersome. This is particularly true of intercom installation which serves up to 8 users.

The relative costs of implementing a TDM system versus an SDM system was evaluated by costing the electrical components of each approach. Only differential costs were tabulated. For instance, at the crew station each approach requires power supplies, MIC amps and phone amps. The TDM approach, however, requires additional CVSD encoders and digital TDM circuits, while the SDM approach requires a differential analog amp and line drivers for the binary coded audio select signals. The cost of these additional circuits was tabulated for each module within the intercom system. In addition, the relative costs of connectors and cables for each approach were tabulated.

The cost differential for each approach was then calculated on the basis of these additional component costs. This calculation is summarized in Table 4-III.

Table 4-III. TDM Versus SDM Component Cost

System Module	TDM	SDM
Crew Station (I/O) 7 Modules	Additional Circuits: TDM CMOS Interface Networks Δ Cost = \$35.70	Additional Circuits: Analog Switch, Line Receivers, Diff Analog Amp Δ Cost = \$31.50
Crew Station 4 Units	Additional Circuits: TDM CMOS Interface, CVSD Encoder/Decoder Δ Cost = \$96.80	Additional Circuits: Line Drivers and Differential Analog Amp Δ Cost = \$8.00
Radio XMIT Select Module	Additional Circuits: 7 CVSD Decoders Δ Cost = \$56.00	No Additional Cost.
Radio RCV Module	Additional Circuits: 5 CVSD Encoders Δ Cost = \$40.00	No Additional Cost
Timing Control	Additional Circuits: CMOS Timing Circuits Δ Cost = \$3.40	
Connectors	4-Wire Bulkhead and Cable Connectors Δ Cost = \$49.00	10-Wire Bulkhead and Cable Connectors Δ Cost = \$103.48
Cable	4-Wire Shielded Cable Δ Cost = \$23/100	10-Wire Shielded Cable Δ Cost = \$50/100
TOTAL COST	TOTAL ADDITIONAL COST = \$303.90	TOTAL ADDITIONAL COST = \$192.98

The results of this cost analysis show that there is a \$111 additional cost in bill of material when a TDM system is implemented versus an SDM system. These costs were based on the use of MIL-STD-883, Class C parts. As explained earlier in Section , it is felt that the reliability of Class C parts is acceptable if they are purchased from a reliable vendor and they are operated at a lower than maximum V_{dd} voltage such as the +6V DC being proposed for the current TDM system. The relative cost impact of having to use Class B parts is illustrated by the relative cost quotes received by ITT-A/OD for CMOS circuits. For a MC-4013 dual D-type flip-flop the cost for a Class B versus Class C component in quantities of 50,000 is \$3.60/unit versus 32¢/unit. For a larger scale integrated circuit such as a MC-4015 dual 4-bit shift register the relative cost for Class B versus Class C is \$8.00/unit versus 58¢/unit. It is clear that the use of Class B components is entirely unrealistic from a cost point of view and present vendor reliability data shows that the use of Class C components is perfectly acceptable.

In the above analysis the relative assembly costs for a TDM versus SDM system were not considered. It is felt that relative costs for assembly of a TDM crew station I/O versus an SDM crew station I/O PC card is about equal. This is also true of other intercom modules. It is felt that the assembly of cables and connectors for the SDM system is appreciably higher than for TDM system cables. At the present time an investigation is being made to determine the costs of cables in the present AN/VIC-1 system and the expected cost of cables for future intercom systems. It is felt that cable costs are a significant factor in overall system cost. If significant savings can be gained by utilizing 4-wire TDM cables versus 10-wire SDM cables, then the utilization of a TDM system will become a viable and cost effective approach.

5.0 AUDIO ACCESSORY INTERFACES

During the past reporting period, study efforts were initiated to determine what, if any, circuits could be developed to improve the performance of audio accessories when operating in conjunction with the intercom system. This effort was directed towards improving the voice signal-to-noise ratio when operating in high vehicle noise environments.

The first part of this study effort was directed toward determining the degree of noise interference at points within the intercom system. Critical points considered were:

1. Background Noise at Users Headphone - Data was evaluated to determine the degree of interference at the user's headphone. This data was used to determine the audio power which must be delivered by user's headphones to provide adequate voice intelligibility in a high background noise environment.
2. Background Noise Interference Entering System via User's Microphone - Data was evaluated to determine the level of noise entering the intercom system via user's microphones. Tests were performed to evaluate the background noise rejection of present headset microphone and circuits were built to determine if high pass filtering would provide additional noise rejection. Data was evaluated to determine what effects background noise had on voice intelligibility.

The following subsections discuss in detail the results of the above study efforts and propose circuit designs which may be implemented to improve intercom performance in a high noise environment versus the present intercom system. The principal results of this study effort were:

1. Headphone Design - Proper design of earmuffs for user headsets will provide the high degree of noise rejection necessary to optimize SNR at the receive end. Use of proper earmuffs will reduce the background noise at the user's ears and thus require a lower output power from the headphone. This will prevent damage to the user's hearing.
2. Microphone Amplifier - Present noise cancelling microphones used with military headsets provide poor noise cancelling performance at lower frequencies. The present intercom system (AN/VIC-1) provides low frequency

response down to 30 Hz. Insertion of a high pass filter at 300 Hz in the future intercom system will provide an additional 3 dB decrease in noise power entering the intercom system via present microphones. An improved noise cancelling microphone design would also reduce the level of low frequency noise interference.

Headphone Amplifier Design

The design of the headphone amplifier for future intercom systems was evaluated in the past quarter in terms of the required audio power necessary to provide adequate SNR for the user in a high noise environment. The background noise environment utilized in this study is based on the noise background within a M113A1 armoured personnel carrier. The ambient noise level for this vehicle was measured by ECOM and data was presented to ITT-A/OD on November 17, 1977. The ambient noise level was measured in 1/3 octave frequency bands. The ambient noise data is tabulated in Table 5-I for 1/3 octave bands and it is also converted to spectral levels in the same table. The total ambient power level calculated for the given data is +116 dB. The spectral level of the noise is plotted in Figure 5-1. Also shown in this figure is the attenuation characteristic of good earmuffs. ⁽¹⁾

The ambient noise level for the user with earmuffs is shown to be significantly reduced in Figure 5-1. The performance of the earmuffs shown in this figure is excellent. The noise rejection performance of earmuffs on army headsets is not known at this time. The total noise power reaching the users ears is +99 dB for the given set of earmuffs. Given this set of noise level conditions and earmuff attenuation characteristics, it is desired to know the required sound pressure level of the voice signal to provide good voice intelligibility. The articulation index was calculated for a voice system which delivers a long term average voice level of +105 dB. The idealized male voice spectrum for +105 dB level voice signal is plotted in Figure 5-1. The articulation

(1) Zwislocki, J. J., Ear Protectors in "Handbook of Noise Control", Chap. 8 (C.M. Harris, ed.) McGraw-Hill, New York, 1957.

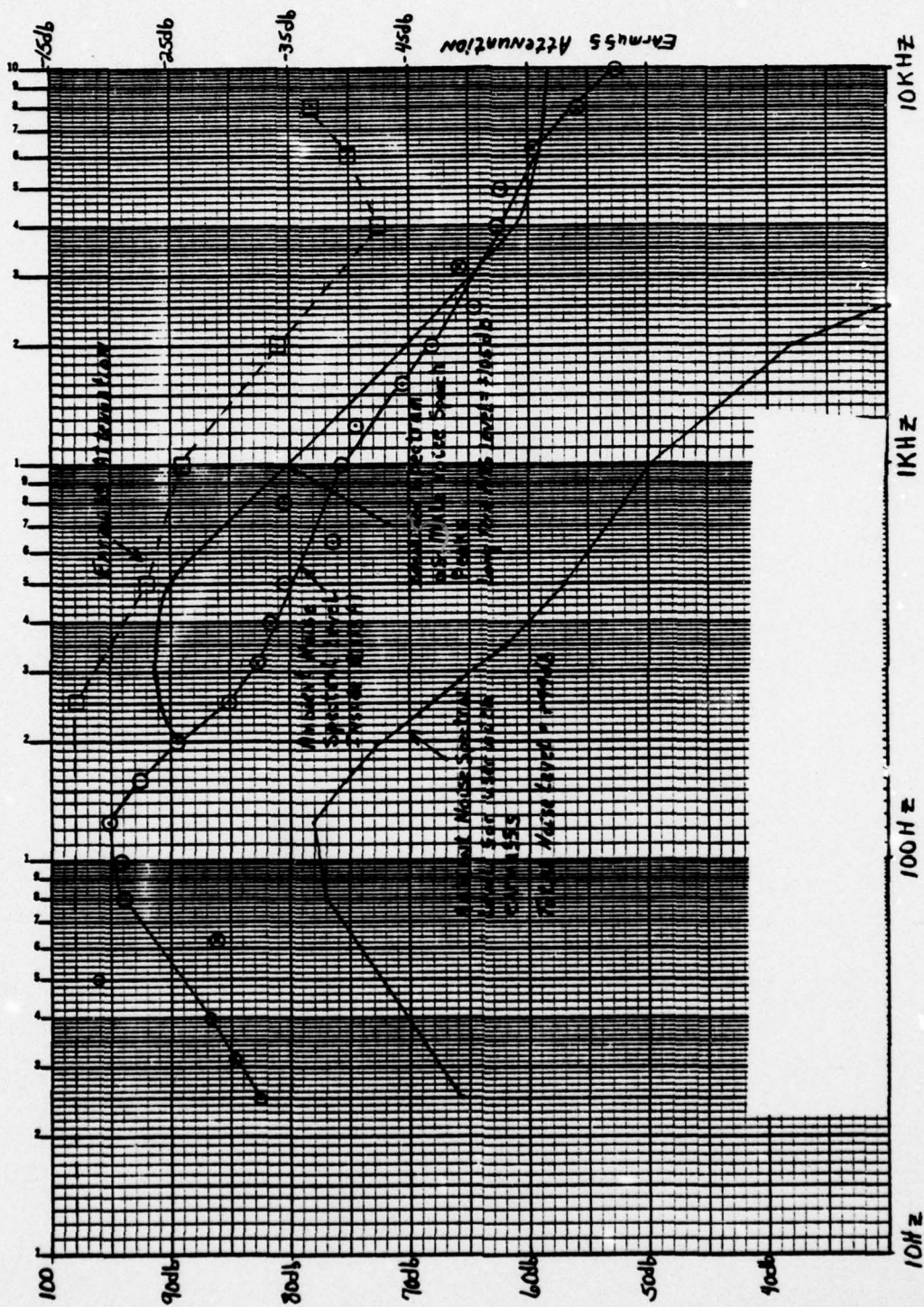


Figure 5-1: Ambient Signal and Noise Levels at User Headphones

Table 5-I. 1/3 Octave and Spectral Level of Ambient Noise in M113A1

1/3 Octave Center Freq.	1/3 Octave Bandwidth	1/3 Octave Noise Level	1/3 Octave to Spectral Conversion Factor	Spectral Noise Level
25 Hz	5.6 Hz	90 dB	- 7.48 dB	82.5
31.5	7.5	93.5	- 8.75	84.75
40	9.5	96.5	- 9.77	86.7
50	11	106.5	-10.4	96.1
63	15	98	-11.7	86.3
80	19	106.5	-12.8	93.7
100	22	107.5	-13.4	94.1
125	28	109.5	-14.4	95.1
160	39	108.5	-15.9	92.6
200	44	106	-16.4	89.6
250	56	102.5	-17.5	85
315	75	101.5	-18.8	82.7
400	95	101.5	-19.8	81.7
500	110	101	-20.4	80.6
630	150	98	-21.7	76.3
800	190	103	-22.8	80.2
1000	220	99	-23.4	75.6
1250	280	99	-24.4	74.6
1600	390	96.5	-25.9	70.6
2000	440	94.5	-26.4	68.1
2500	560	92	-27.5	64.5
3150	730	94.5	-28.8	65.7
4000	950	92.5	-29.8	62.7
5000	1120	92.5	-30.4	62.1
6300	1500	91	-31.7	59.3
8000	1900	88.5	-32.8	55.7
10000	2200	86	-33.4	52.6

TOTAL Ambient Noise Level = +116 dB

index for this voice spectrum and noise spectral level was calculated in accordance with the American National Standard Methods for the calculation of the Articulation Index. The 20 band method was utilized. The resulting AI was 0.9 which is excellent.

The results of this analysis show that acceptable voice communications can be provided in a high background noise environment if good earmuff protective devices are used. For the set of conditions analyzed in Figure 5-1 it is necessary to determine what power level from the headphone amplifier is required to deliver long term average voice level of ± 105 dB at the output of the headphones. At the present time the overall characteristics of military headphones are not known. The following headphone characteristics are assumed until more reliable information can be obtained.

Headphone Impedance: 500 to 600-Ohms. Each earpiece is 1000-ohms and they are wired in parallel

Headphone Sensitivity: $+105 \text{ dB} \pm 5 \text{ dB}$ (SPL) at 1 kHz for 1mW. input power. Given this data, the headphone amplifier must supply a long term average power of 1 mW at 500-ohms to the headphone. Due to the high peak-to-RMS nature of the voice signal, the phone amp will also have to provide high peak powers. According to data gathered by Dunn and White, ⁽¹⁾ speech peaks exceed the long term average by 12 dB 10 percent of the time. To provide good linearity in amplifying the voice signal, the phone amp should be capable of linear output levels up to 16 mW. At the time of this quarterly report a phone amplifier has been breadboarded in conjunction with the CVSD network breadboard which is capable of continuous output power levels up to 200 mW. This amplifier should easily be capable of handling voice signals, whose average power level are 1 mW on a distortion free basis. The high level power capability of a 200 mW phone amp is high in comparison to the 16 mW peak power requirements specified above. This power level is tentatively specified at this time to cover noise environment cases

(1) Dunn, H.K. and White, S.D., Statistical Measurements on Conversational Speech, J. Acoust. Soc. Am, 11.278 (1940)

which exceed +116 dB and those headsets which do not provide the noise attenuation shown in Figure 5-1. Given a peak power capability of 200 mW, means that peak sound pressure levels at the user's headphone could approach ± 128 dB. Sound pressure levels of this intensity are potentially damaging to the user's hearing.

To reduce the effects of exposure to these high noise levels it is recommended that ear plugs be worn by the user. At high peak voice levels the speech peaks can overload the ear and result in degraded speech intelligibility even though the input SNR is quite high. Tests by Kryter ⁽²⁾ have shown that significant improvements in voice intelligibility can be made by employing ear plugs in a high noise environment. Percentage improvements of up to 20 percent in PB-word intelligibility scores have been measured at speech and noise levels of 108 dB and 105 dB respectively. On the basis of the above analysis, the following recommendations are made to improve the voice intelligibility of the intercom system at the receiving end:

1. Linear 200 mW Headphone Amp - Peak audio output power levels of up to 200 mW are required to provide a positive SNR to user in adverse noise environments. Since sound pressure levels of up to ± 128 dB are possible at this power level, it is recommended that each user be equipped with earplugs.
2. Headphone Earmuffs - Good headphone earmuffs will contribute significantly to the improvement of system voice intelligibility.
3. Earplugs - In high noise environments it is recommended that earplugs be used to protect the user's hearing and also to provide improved voice intelligibility.

In addition to these recommendations, consideration should be given to designing the volume control for each user such that the control is detented when a given output sound pressure level is ex-

(2) Kryter, K.D. "Effects of Ear Protective Devices on the Intelligibility of Speech in Noise", Journ. Acoust. Soc. Am, 1946, pp 18, 413

ceeded. Such an approach would give the user some degree of protection against high sound pressure levels. A typical volume control would employ two volume ranges of volume off to 1 mW and 1 mW to 200 mW. The two volume ranges would be separated by a noticeable detent in the operation of the control. Such a design would provide an indication to the user when he is operating at potentially damaging sound pressure levels. Operation above the volume control detente would indicate to the user that earplugs should be in place to protect hearing. For young soldiers with relatively good hearing, such protection techniques would minimize degradation in hearing. For older soldiers whose hearing loss over the years has been significant, the intercom is still capable of providing the high volume levels necessary.

Microphone Amplifier Design

The design of the intercom microphone amplifier was evaluated in the past quarter in terms of the vehicular noise environment and the performance of present and future military noise cancelling microphones. Calculations were made and tests were run to determine whether high pass filtering of the microphone signal could significantly reduce noise interference levels. The noise spectral levels within M113A1 were used in the following analysis.

At the present time the only data available on the noise cancellation performance of microphones is that reported by Vought Corp.⁽¹⁾ on their NCMA-102 microphone. The noise spectrum level within a M113A1 vehicle and the noise rejection performance of the NCMA-102 is plotted in Figure 5-2. Also plotted in this figure is the effective noise interference after cancellation. The NCMA-102 microphone sensitivity is -90 dB V/ μ bar. This sensitivity would result in an average voice level of -57 dBV or 1.4 mV (long term RMS avg) and voice peaks of 5.6 mV (peak) at the MIC output. The long term RMS noise level at the microphone output would be 0.44 mV (RSM) for the given background noise level and microphone noise cancellation per-

(1) Brouns, A.J. (Linear Noise-Cancelling Microphone), Vought Corp., ECOM 75-0140-F, June 1976

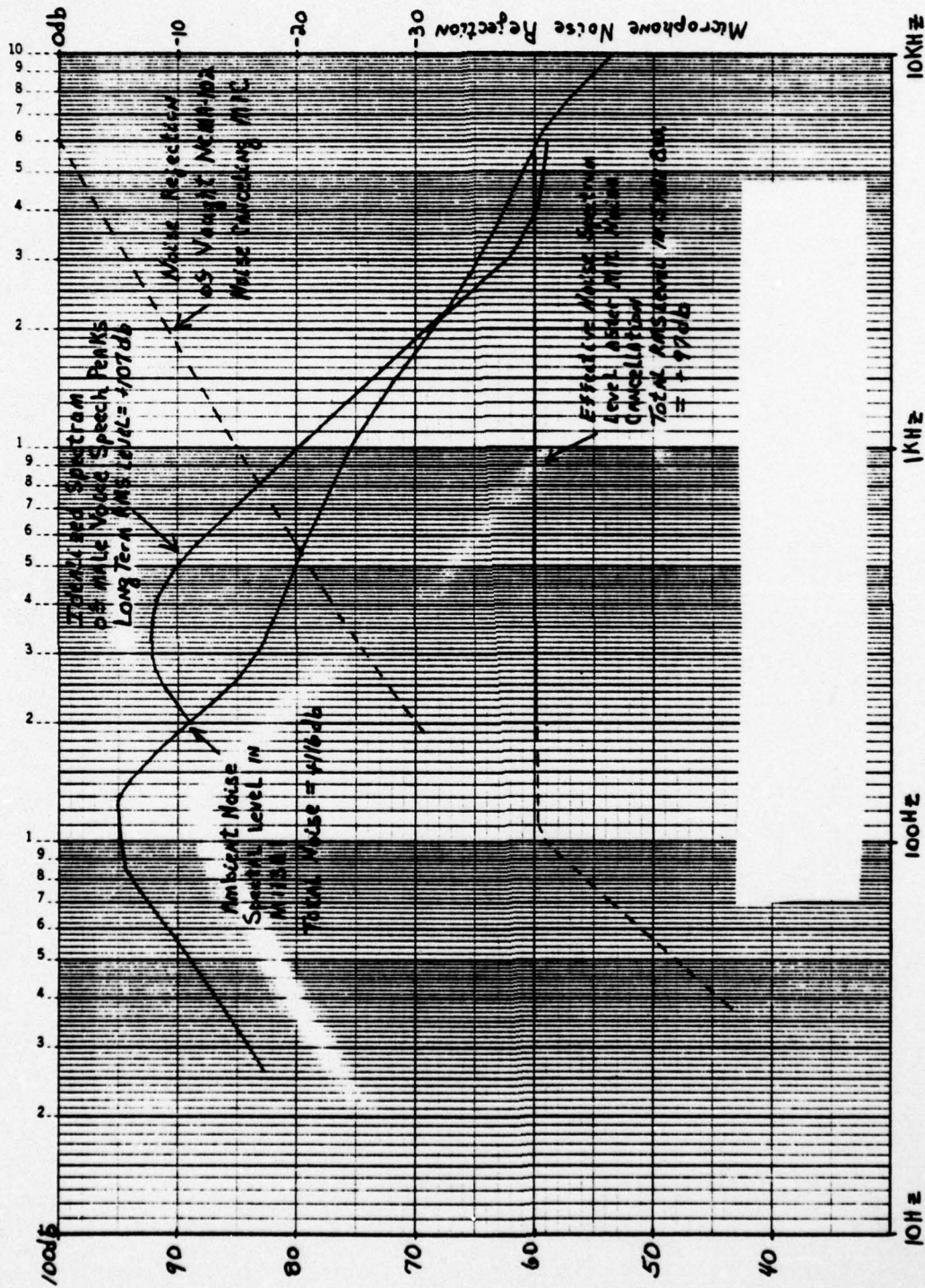


Figure 5-2: Noise Cancellation Microphone Performance

formance. The articulation index of an intercom system operating under these conditions was calculated for an operating bandwidth of 0 Hz to 5 kHz. The resulting AI was 0.446.* This analysis and resulting calculation shows that even with a good noise cancelling microphone and at a fairly high voice input level, the resulting AI is marginak in a vehicle noise environment of ± 116 dB. Higher voice input levels in the form of shouting is required by the user to significantly improve the AI of the intercom system. This brief analysis along with the preceding assessment of noise interference at the headphone illustrates what is already a well known fact: i.e. noise interference at the microphone input is the limiting factor in the voice intelligibility of the present intercom system and any future intercom system.

After performing this theoretical evaluation of the Vought Corp. NCMA-102 microphone, tests were developed to measure the performance of present military microphones such as the M-138 microphone assembly. To perform this evaluation the test setup shown in Figure 5-3 was constructed. The environmental noise within the M113A1 was simulated by shaping and filtering the white noise output from a GR1390-B noise generator. This noise was then amplified to a high acoustic level, which is measured by the GR-1933 sound level meter. The calibrated microphone for the GR-1933 was placed next to the microphone under test, such that each microphone was exposed to the same sound pressure level.

The output of the M-138 was fed through a MIC amp to an RMS voltmeter. The RMS voltage of the amplifier microphone noise was measured with and without a 300 Hz high pass filter. The results of these measurements are listed as follows:

*An AI in the range of 0.3 to 0.7 results in communication which is slightly difficult to satisfy. At an AI of 0.5, 98 percent of sentences are heard correctly.

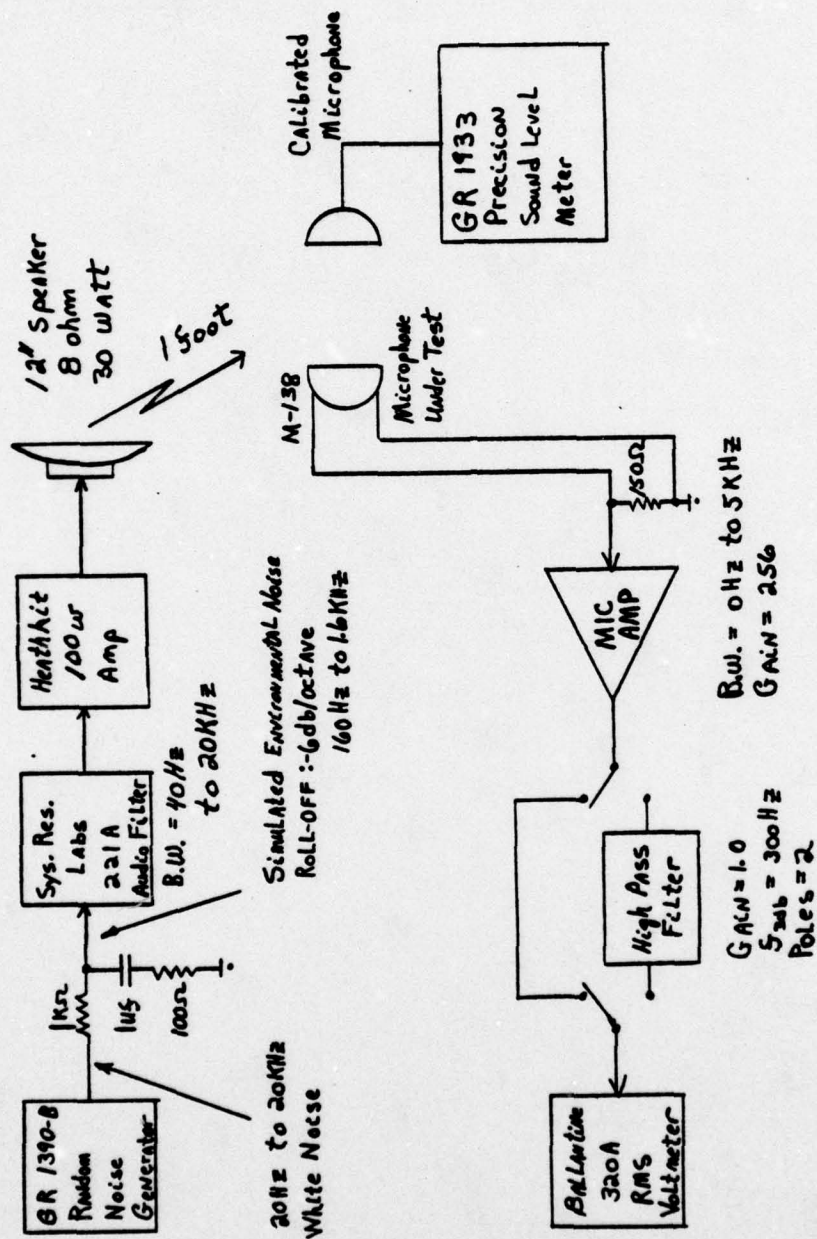


Figure 5-3: Environmental Noise Test Set-up for Evaluating Noise Cancelling Microphone

Microphone Type	Sound Pressure Level	MIC AMP RMS Voltage	
		W/O High Pass	With High Pass
M-138 Military Noise Cancelling Mike	90 dB	13 mV (RMS)	10 mV (RMS)
	100	40 mV (RMS)	30 mV (RMS)
Telex CS-61 Headset	90 dB	7.8 mV (RMS)	7.8 mV (RMS)
	100 dB	20 mV (RMS)	20 mV (RMS)
Vought Corp. NCMA-102	90 dB	5.6 mV (RMS)*	5.3 mV (RMS)*
	100 dB	17.75mV (RMS)*	16.71mV (RMS)*

*This is the predicted performance for the NCMA-102 based on available test data.

In the above test data the relative levels for each microphone tested is different. This is due to relative differences in microphone sensitivity for each device. The important thing to note in the above data is that for the Telex CS-61 data and the predicted NCMA-102 data, there is no significant change in RMS noise level when the high pass filter is added. For the present M-138 microphone, the addition of the 30 Hz high pass filter provides an additional 3 dB decrease in noise level. Whether this test response for the M-138 is characteristic of all M-138 microphones is not known. These tests do indicate that in those vehicle environments where there is a high level of low frequency noise interference, such as in the M113A1, then the employment of a 300 Hz 2-pole high pass filter in the MIC AMP could reduce the level of noise interference. This is particularly true if the M-138 microphone is in use.

A brief look was taken at the present AN/VIC-1 intercom system to determine if any steps had been taken to incorporate high pass filters or coupling networks in the respective MIC amp circuits. Analysis of AN/VIC-1 circuits showed that the highest break frequency for AN/VIC-1 coupling networks was 30 Hz. This does not include the low frequency response of the phone amp output transformer and the respective headphones. This result shows that simple decreased in the values of AC coupling capacitors could provide noise rejection within the AN/VIC-1 system.

Voice Keying Networks (VOX)

In the past reporting quarter, several possible voice keying circuits were looked at for possible use in the intercom system. VOX circuits are being investigated for possible use within the intercom system to provide the user hands-free operation of intercom audio accessories. The use of VOX in combination with wireless intercom techniques could improve dramatically the mobility of crew members within armoured vehicles. The use of VOX would allow the user to devote the use of his hands to full time operation of vehicle controls. This would improve user performance in the area of vehicle operation. In selecting and designing a VOX network for operation in the intercom system, certain key operational requirements and features should be considered as follows:

1. Reliable Keying - The VOX circuit should key reliably within 50 msec of the start of a word. Rapid keying will ensure good voice intelligibility and ensure single word commands are not misinterpreted by crew members such that their safety is endangered. Reliable keying should be possible in adverse high noise environments.
2. False Keying - The probability of false keying should be minimal due to noise and vibration. Particular attention should be paid to designing a VOX network which cannot be spoofed by voice-like noises within the vehicle.
3. VOX Operation - Selective operation of the VOX circuit should be possible such that the user can disable the VOX at any time and operate in a manual PTT mode. The VOX network operation in Intercom Only and Radio modes should be selectable by the user.
4. Cost - The incorporation of the VOX network within the intercom system should not heavily impact the system cost. The circuit design should be simple and economical. Consideration should be given to making the VOX circuit an optional crew station feature, which is installed only at those crew stations which require VOX operation. Operation of VOX as an optional add-on module or plug-in PC board would reduce significantly the cost impact on the system.

Five VOX networks were investigated for possible use within the intercom system. These networks were as follows:

1. Fixed threshold voice detection and keying network
2. Adaptive threshold voice detection and keying network
3. CVSD pattern detection and key network
4. Radiometer or energy comparison voice detection and keying network
5. Zero crossing voice detection and keying network

In the above approaches, breadboard models of networks number 2, 3 and 4 were built and tested. The fixed threshold approach was not built since it could easily be evaluated by disabling the adaptive operation of Network No. 2. The zero crossing detection approach was not built since its operation closely resembles the operation of Network No. 4 in that both techniques measure the frequency content of the voice signal to detect its presence.

The relative performance of the three VOX networks, which were breadboarded, were evaluated by measuring the attack time of each network for various word inputs. Their false keying performance was also evaluated under high background noise conditions. The adaptive threshold VOX network offered the best attack time of 17 msec average for a 26 word vocabulary. The attack time for all words was less than or equal to 50 msec. It was also immune to false keying at peak voice to RMS noise ratios of 10 dB. The radiometer VOX network offered the next best performance with an average attack time of 34 msec for a 26 word vocabulary. The radiometer VOX network, however, was unable to detect rapidly words that begin with a "s" sound such as in the word SIERRA. The radiometer VOX network also provided excellent false keying performance. The performance of the CVSD pattern detection VOX was very poor in terms of attack time, in that certain words were totally missed. No extensive data was taken on this VOX network.

The following subsections present a description of each of the VOX networks tested and a summary of their relative performance is then presented.

Adaptive Threshold VOX

A block diagram of the adaptive threshold VOX network is shown in Figure 5-4. The implementation of this VOX network is similar in concept to the digital voice activated switch developed at COMSAT labs.⁽¹⁾ An adaptive threshold VOX network was chosen for testing in preference to a fixed threshold VOX network, due to the following limitations inherent in a fixed threshold VOX:

1. Noise Immunity - To provide good noise immunity and prevent constant false keying, the voice detection threshold must be set high. Under varying noise levels common in a vehicle, the voice threshold is always set at the highest level for worst case noise levels.
2. Voice Detection - Voice detection for a fixed level VOX is at best marginal since the threshold is set to a high level which avoids false keying in high noise environment. Under quiet conditions the user must still shout to key the VOX. Even when shouting words which begin with "S" sounds such as SIERRA will not key the VOX network.

The adaptive threshold VOX overcomes these shortcomings and provides an optimum voice threshold level under a wide range of varying noise levels. In Figure 5-4 the voice signal from the users MIC amp is rectified and fed to two level detectors. At the noise threshold level detector a tracking D/A converter is used to track the noise peaks. The time constant of the integrate and dump (I&D) network is set such that if the incoming noise peaks exceed the noise tracking voltage more than 10 percent of the time, the up-down counter is incremented and the respective D/A noise tracking voltage is increased. The D/A converter is updated at a 160 Hz rate unless the voice threshold level detector is triggered. The presence of voice signals thus disables operation of the up-down counter. The voice threshold voltage is always 50 percent

(1) Jankowski, J.A., "A New Digital Voice Activated Switch", COMSAT Technical Review, Vol. 6, No. 1, 1976

higher than the noise tracking voltage. This ratio of noise and voice thresholds prevents false keying by noise peaks but is very sensitive to incoming voice signals. The adaptive VOX network in Figure 5-4 provides the following key operational features:

1. Update rate of 160 Hz provides for rapid tracking by D/A converter of noise levels within vehicle.
2. Updating of D/A converter is disabled during active voice periods such that threshold level is held constant during periods of voice activity.
3. The voice threshold level is always set at the optimum level for detection of voice signals. This level provides a low false keying rate due to noise, but allows the detection of low level voice sounds such as present in the word SIERRA

Radiometer VOX Network

A block diagram of the radiometer VOX network is shown in Figure 5-5. The principle of operation for this VOX network is based on the relative spectral shape of voice signals versus interfering noise. The spectrum of the typical male voice spectrum was shown in Figure 5-2. In that figure the voice spectrum rolls off at about 10 dB/octave from 500 Hz to 4000 Hz. During speech periods, the amount of detected energy in filter band from 300 Hz to 1500 Hz is much higher than the voice energy in a 1500 Hz to 2500 Hz frequency band. This fact can be used to detect the presence of a voice signal. During non-voice periods, the input to the radiometer VOX network is background noise interference. If the noise spectrum is flat and the noise bandwidth of the two radiometer filters are equal, then the VOX network will not be triggered. Good false keying performance for the radiometer network is dependent on the input noise being flat noise. In Figure 5-2, the interfering noise spectrum within the M113A1 vehicle is not flat but is very similar in shape to the voice spectrum. In Figure 5-2 it is shown however, that the M113A1 noise spectrum is flat in nature after being passed through the noise cancelling microphone. This fact results in the requirement that proper operation of a radio-

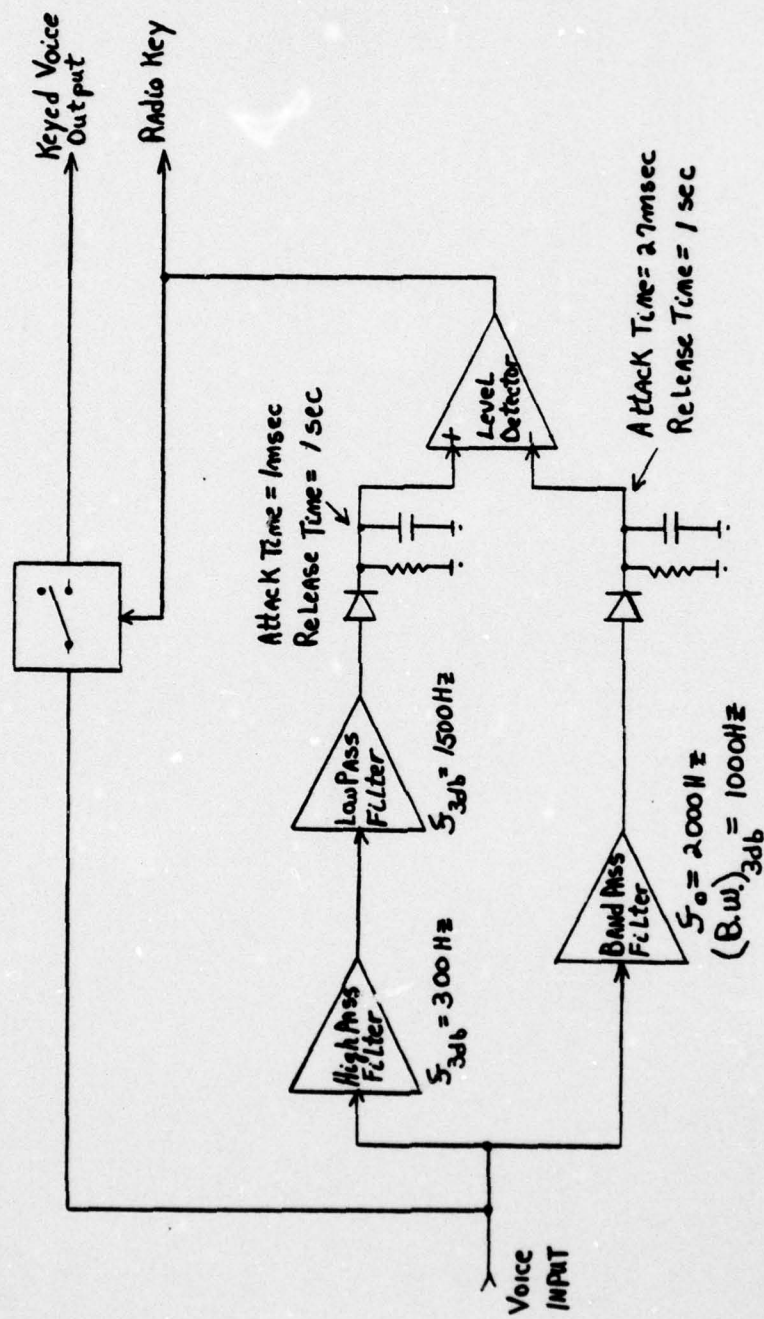


Figure 5-5: Radiometer VOX Network

meter VOX within an armoured vehicle will depend to a high degree on the performance of the noise cancelling microphone. Preliminary tests of a radiometer VOX and noise cancelling microphone were performed in the lab using the noise environment test setup shown in Figure 4-8. Test results showed that the radiometer VOX was immune to false keying at noise levels up to +110 dB when operating with the Telex CS-61 headset microphone.

In general the radiometer VOX provided fast attack times, but for certain sounds the performance was marginal. This was particularly true of unvoiced sounds such as "S" which starts words such as SEEK, SIERRA, etc. Words such as these suffered severe front end truncation. This poor performance is due to the fact that the frequency content of these sounds is in the range of 2000 Hz to 3000 Hz. Also, these sounds are very noiselike in nature and cannot be distinguished from background noise interference. As a result of evaluating the radiometer VOX network, the following operating advantages and disadvantages were noted:

1. Simple Hardware - The radiometer VOX can be implemented with very simple hardware with respect to the Adaptive Threshold VOX.
2. Good Immunity to False Keying - If the interfering background noise spectrum is flat in nature, the radiometer VOX offers good immunity to false keying. Low frequency noise would degrade performance.
3. Marginal Attack Time - The radiometer is unable to detect certain high frequency components of certain words. This results in the truncation of the front end of these words and can lead to misinterpretation of the word.

CVSD Pattern Detection VOX

Due to the fact that CVSD is being considered for encoding/decoding of analog voice in an Intercom TDM voice distribution system, it was decided to investigate whether bit patterns existed in the CVSD output data stream which were indicative of voice activity versus

input noise interference. The digital output of a CVSD encoder generates a random output bit pattern, but this pattern is characterized by long series of 1's and 0's during high amplitude voice inputs. During the input of low level voice signals or noiselike signals, the CVSD digital output is characterized by alternating patterns of 1's and 0's.

A simple variable length shift register and AND gate decoder network was set up at the output of the MC-3418 CVSD encoder. The decoder could be set to detect consecutive patterns of 1's or 0's from 4 bits to 8 bits in length. Test results showed that a decoder setting of six consecutive logic 1's or 0's was necessary to provide immunity to false keying on noise. With this decoder setting the pattern detection method worked reliable for words which began with hard consonant sounds such as DOG, GUN, etc. The pattern detection network, however, failed to detect such words as THESE, SHOOT and other words which do not exhibit low frequency high amplitude characteristics. Extensive testing was not performed on this VOX network because of its poor performance with certain words.

VOX Network Evaluation and Testing

Tests were made to evaluate the attack time performance of the Adaptive threshold and Radiometer VOX. These tests included a 26 word vocabulary test to measure average attack time and to determine the existence of words which posed particular detection problems. Test tapes were run to provide a subjective evaluation and noise interference tests were made to evaluate false keying performance. Also evaluated was the dynamic voice range over which each VOX network would reliably be operated.

To test the attack time of each VOX network, the 26 word international word-spelling alphabet was used. Its choice was convenient and purely arbitrary. Whether the use of this particular word list is optimum for testing VOX networks is not known. It is felt that this word list covers most typical voice sounds which might eventually key up an Intercom VOX network.

The results of attack time tests for the two VOX networks is shown in Table 5-II. These test results show that the Adaptive Threshold VOX provides much better performance than the radiometer network. The effect of front end clipping on voice intelligibility has been evaluated by Ahmed and Fatechard.⁽¹⁾ Their work showed that front end clips of up to 30 msec are acceptable for plosives and fricatives (i.e. plosives are words such as Bravo and Papa, while fricatives are words such as foxtrot and victor). For these words, both VOX networks were within the 30 msec except for the word PAPA. Ahmed and Fatechand also found that clips of up to 40 msec were acceptable for semi vowel sounds while clips longer than 50 msec will significantly reduce articulation scores. On the basis of criteria set up by Ahmed and Fatechand it is felt that the Adaptive Threshold VOX provides acceptable performance, while the Radiometer VOX is marginal to unacceptable in performance.

A subjective analysis of the two VOX networks was made by playing a test tape of the 26 word vocabulary through each VOX and then listening to the VOX output. In general, the subjective evaluation confirmed the attack time test results. All words passed through the Adaptive Threshold VOX were heard correctly while the word SIERRA was heard incorrectly with the radiometer VOX.

Additional tests were run on both VOX networks to evaluate performance in a high noise background and over a wide dynamic voice range. Both VOX networks operated reliably without false keying at voice peak to RMS noise ratios of 10 dB or less. Each VOX network was also capable of operation over an input dynamic range of 20 dB.

The use of a VOX network in the intercom system remains to be determined at this point in the study. Results to date show that an adaptive threshold VOX provides acceptable performance when operating in a noisy environment characterized by flat noise. Questions

(1) Ahmed, R. and Fatechand, R., "Effect of Sample Duration on Articulation of Sounds in Normal and Clipped Speech", Journal of Acoustical Society of America, Vol. 31, 1959, pp 1022-1029

Table 5-II. VOX Network Attack Time
Performance Test

Test Word	Adaptive Threshold VOX Attack Time	Radiometer VOX Attack Time
1. Alpha	5 msec	10 msec
2. Bravo	10	20
3. Charlie	20	60
4. Delta	10	20
5. Echo	5	5
6. Foxtrot	20	30
7. Golf	20	10
8. Hotel	30	50
9. India	10	20
10. Juliet	40	50
11. Kilo	10	50
12. Lima	20	40
13. Mike	5	5
14. November	5	10
15. Oscar	5	20
16. Papa	50	50
17. Quebec	50	40
18. Romeo	10	30
19. Sierra	30	140
20. Tango	20	70
21. Uniform	10	60
22. Victor	10	25
23. Whiskey	10	20
24. X-Ray	5	5
25. Yankee	20	50
26. Zulu	50	70
AVERAGE ATTACK TIME	$T_{avg} = 17 \text{ msec}$	$T_{avg} = 35 \text{ msec}$

which remain to be answered on the application of a VOX network in inter-com systems are listed as follows:

1. Environmental Noise - False keying performance has been evaluated in the lab with conventional test equipment. Although performance was good, the VOX network should be evaluated in a real-world vehicle operating environment to assure there are no unique vehicle noise characteristics which cause false keying.
2. User Safety - In the day-to-day operation of an army vehicle, there are one word commands among crew members which coordinate the operation of the vehicle. The safety of the crew members depends on reliably receiving these commands. Truncation of key command words by the VOX network could lead to word misinterpretation. This could pose a safety problem within the vehicle. Command words such as POWER prior to turret reotation must be received correctly by each crew member such that hands are in a safe position during turret rotation. Such safety considerations with respect to use of a VOX must be discussed with the user.
3. Cost Effectiveness - It remains to be determined if the mobility provided the user by the VOX is significant with respect to added system cost.

ACTIVITY FOR NEXT QUARTER

The next quarter activity will focus on the system design. Included is design reliability, nuclear hardening, and TEMPEST consideration will be incorporated into the system.

Installation of the system into a tracked vehicle will also be considered. This will include cable routing, connector placement on control boxes, and cable size. Wireless testing to correlate calculated distances to actual data.